

**Water Year 2006
Overview of Surface Water
Monitoring Data for SC, SAR and Flow
in the Powder River Watershed**



This cover photo shows Streamflow-gaging station 06317000, Powder River at Arvada, Wyo.
(photo obtained from <http://pubs.usgs.gov/wri/wri014279/html/report.htm>)

**Prepared by: Andrew L. Bobst, Hydrologist, BLM-Miles City Field Office
August, 2007**

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Introduction

When Coal Bed Natural Gas (CBNG) is developed, the methane must be allowed to desorb from the coal so that it can flow to production wells. This desorption is typically achieved by pumping groundwater from the coal bed aquifer to reduce the hydrostatic pressure within the coal seam (allowing the methane to desorb) and create a pressure gradient within the aquifer. This pressure gradient causes methane to flow towards the pumping wells.

The management of CBNG water may result in it being introduced into surface waters. CBNG water in the Montana portion of the Powder River Structural Basin (PRB) is moderately saline, having a Specific Conductance (SC) on the order of 2,000 microSiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$). SC is the ability for water to conduct a current at 25 degrees Celsius, and it is proportional to salinity. High salinity irrigation water may result in decreased crop yields depending on the crop being grown (See Figs. 1 and 3). The technical definition of Electrical Conductivity EC is “the ability of water to conduct a current” (Stednick, 1991); however the Montana Department of Environmental Quality (MDEQ) regulations define EC as “the ability of water to conduct an electrical current at 25°C”. Since this is the same as the technical definition of SC, the SC values discussed in this report are directly comparable to the EC standards.

CBNG water in the Powder River Basin is a sodium-bicarbonate (Na-HCO_3) type water. This dominance of sodium cations causes CBNG water to have a high Sodium Adsorption Ratio (SAR; which is a complex ratio of Na to Ca+Mg); typically between 30 and 60 (ALL, 2001). High SAR values may cause impacts to soil structure, and impair the ability for clay rich soils to infiltrate water (see Figs. 2 and 3). There is also little sulfate in water from productive coal seams (VanVoast, 2003).

Much of the CBNG produced water in the PRB is managed through treated or untreated discharge to surface waters under National Pollutant Discharge Elimination System (NPDES) permits, implemented under the Clean Water Act. In Montana, NPDES permitting is conducted by the Montana Department of Environmental Quality (MDEQ) under the Montana Pollutant Discharge Elimination System (MPDES) permit program. There were no active MPDES permits for CBNG in water year 2006 in the Powder River Watershed. In Wyoming, NPDES discharge permitting is conducted by the Wyoming Department of Environmental Quality (WDEQ) under the Wyoming Pollutant Discharge Elimination System (WYPDES). Surface discharge, either with or without treatment, and to on and off channel impoundments are the major methods of water management in the Wyoming portion of the Powder River Watershed (McKinley, pers com. 2006).

Large scale CBNG development began in the Powder River structural basin, in approximately 1999; within the first CBNG discharge in Montana occurring in September, 1999. In response to the potential for CBNG development in the Powder River Basin, the MDEQ has developed surface water quality standards for EC and SAR in the Powder River watershed. These standards provide criteria against which to compare the monitoring data. These standards are summarized in Table 1 below. The MDEQ standards have been reviewed and approved by the United States Environmental

Protection Agency (EPA), and therefore have Clean Water Act standing. Also, note that irrigation season standards are different from the non-irrigation season. MDEQ standards are applicable at the Wyoming-Montana state line; however they are not applicable in Wyoming. It should be noted that these values are used solely as a point of comparison; the comparisons in this report do not constitute regulatory determinations.

The Montana Board of Environmental Review (BER) has modified the standards which apply to CBNG in Montana; however this report only considers those standards which were in place in water year 2006. The most substantial change adopted by the BER was to designate EC and SAR “harmful” parameters, which causes non-degradation rules to apply. This change has not yet been approved by the EPA, and so is not in force at this time.

Table 1. MDEQ Standards for EC and SAR in the Powder River Watershed

	Irrigation Season (March-October)				Non-Irrigation Season (November-February)			
Stream	Mean Monthly EC (uS/cm)	NTE EC (uS/cm)	Mean Monthly SAR	NTE SAR	Mean Monthly EC (uS/cm)	NTE EC (uS/cm)	Mean Monthly SAR	NTE SAR
Powder River	2000	2500	5	7.5	2500	2500	6.5	9.75
Little Powder River	2000	2500	5	7.5	2500	2500	6.5	9.75
Tributaries	500	500	3	4.5	500	500	5	7.5

NTE = Not to Exceed

The Interagency Working Group for CBNG in the Powder River Basin (IWG) has identified regional surface water monitoring objectives (see Table 2). The status of the stations in the Powder River Watershed for water year 2006 (10/1/05-9/30/06) are listed on Table 3 below. The locations of the active stations are shown on Map 1. Data collected at these stations included continuous flow, continuous SC, continuous SAR estimation, and analytical sampling. Analytical sampling includes the measurement of flow, field parameters (SC, pH, temperature, etc) and includes the collection of water-quality samples. Although these samples were analyzed by the USGS for many parameters, this report will focus on SC, SAR, and flow. SC and SAR are considered to be the parameters most likely to be affected by CBNG development (MDEQ, 2003b), and SC and SAR in the natural system fluctuate significantly with flow. The monitoring at these stations was funded by the USGS, WDEQ, WSEO, MDEQ, and MDNRC. An expanded set of analytical data are available from the USGS at <http://waterdata.usgs.gov/nwis>.

Table 2: IWG Recommended Surface Water Monitoring Plan

Stream Type	Constituent Class	Sampling Frequency
Mainstem	Streamflow	Continuous
	Field Measurements	12 times per year
	Major Ions	12 times per year
	Suspended sediment	12 times per year
	Primary Metals	12 times per year
	Secondary Metals	2 times per year
	Nutrients	2 times per year
Tributary	Streamflow	Continuous
	Field Measurements	6 times per year
	Major Ions	6 times per year
	Suspended sediment	6 times per year
	Primary Metals	6 times per year
	Secondary Metals	2 times per year
	Nutrients	2 times per year

Data Review

For all sites, please see the figures section for graphical display of the data. Tabulated summary statistics for the sites are provided on Tables 4 and 5 below.

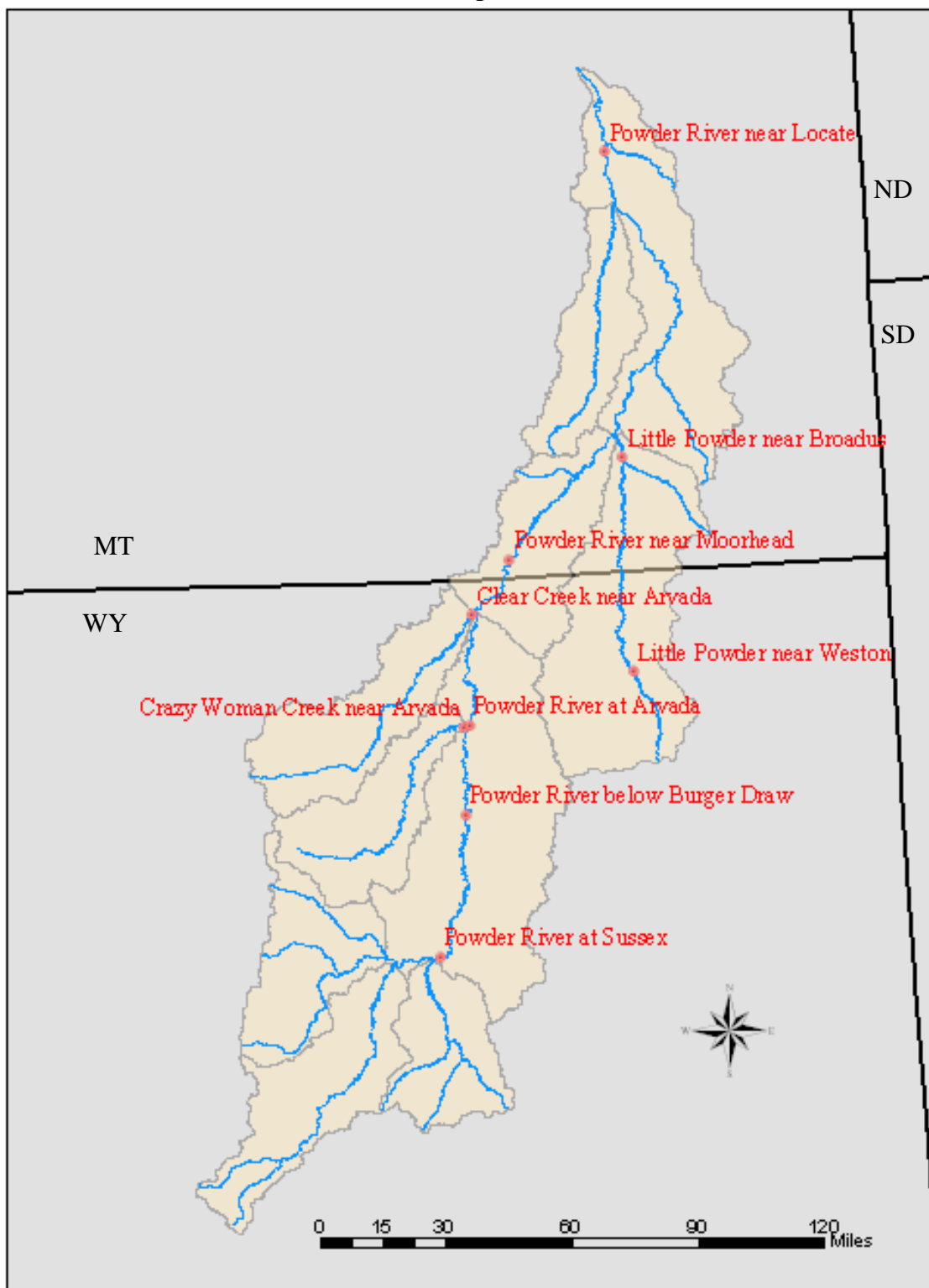
For each station a summary of the mean daily flow, SC, and SAR data collected during water year 2006 is presented. Note that the minimum and maximum values shown represent the minimum and maximum mean daily values recorded; not the minimum of the minimum values, or the maximum of the maximum values. Analytical Flow, SC and SAR data are also presented. Analytical results are compared to the MDEQ “not to exceed” (NTE) surface water standards for EC and SAR where they are applicable. For comparison to the mean monthly EC and SAR standards the mean monthly values are calculated as the simple average of all the mean daily and analytical measurements recorded during each calendar month, so long as at least nine values were available. Note that within the figures section the daily mean and analytical data are combined when discussing the range of values recorded. SC vs. Flow, SAR vs. Flow, and SC vs. SAR with historical data are presented in graphical form to allow evaluation of 2006 data in context.

Table 3: Status of Surface Water Monitoring relative to the IWA Surface Water Monitoring Plan in the Powder River Watershed, Water Year 2006

Site	Continuous Stream- flow	Field measure- ments	Major Ions	Nutrients	Trace elements, primary	Trace elements, secondary	Sus- pended sediment
Powder River, at Sussex	●	●	●	○	⊙	○	○
Powder River below Burger Draw, near Buffalo	○*	●	●	○	⊙	○	○
Powder River, at Arvada	●	●	●	○	⊙	○	○
Powder River, at Moorhead	●	●	●	●	●	●	●
Powder River, near Powderville	○	○	○	○	○	○	○
Powder River, near Locate	●	●	●	●	●	●	●
Crazy Woman at Upper Station, near Arvada	●	●	●	●	⊙	○	●
Clear Creek, near Arvada	●	●	●	○	⊙	○	○
Little Powder River above Dry Creek, near Weston	●	●	●	●	⊙	⊙	●
Little Powder River, near Broadus	○	●	●	●	●	●	●
Mizpah Creek, near Mizpah	○	○	○	○	○	○	○

* Continuous Streamflow is collected at Powder River above Burger Draw.

Map 1



Map 1 shows the Powder River Watershed as it extends from Wyoming into Montana. The locations of the 9 surface water monitoring sites (6 in Wyoming, 3 in Montana), which are the subject of this report, are also shown.

Main Stem Sites

**Table 4: Water Year 2006 Summary Statistics for Mainstem Sites
in the Powder River Watershed**

		Mean Daily			Analytical			Mean Monthly	
		Flow (cfs)	SC (uS/cm)	SAR	Flow (cfs)	SC (uS/cm)	SAR	SC (uS/cm)	SAR
Powder River at Sussex, WY*	n	365	155	155	24	24	24	7	7
	min	2.0	905	0.8	3.7	1050	2.7	1231	2.0
	max	736	6470	19.2	260	6240	20.1	5919	17.4
	mean	102	3281	8.6	92	2855	6.8	3329	8.7
	median	84	3040	7.8	84	2365	5.0	3327	8.6
Powder River below Burger Draw, near Buffalo, WY*⁺	n	365	---	---	12	12	12	---	---
	min	1.3	---	---	3.4	1230	3.8	---	---
	max	660	---	---	241	4280	26.7	---	---
	mean	111	---	---	106	2648	8.6	---	---
	median	94	---	---	104	2460	6.0	---	---
Powder River at Arvada, WY*	n	365	---	---	21	20	21	---	---
	min	0	---	---	9	1390	3.6	---	---
	max	750	---	---	270	3390	11.7	---	---
	mean	119	---	---	129	2314	6.2	---	---
	median	100	---	---	105	2305	5.6	---	---
Powder River near Moorhead, MT	n	365	206	---	24	24	24	8	---
	min	0	917	---	0.6	1120	3.1	1394	---
	max	1000	6090	---	407	3660	9.0	3754	---
	mean	164	2206	---	168	2102	4.6	2276	---
	median	175	2005	---	180	1885	4.1	2019	---
Powder River near Locate, MT	n	365	---	---	12	12	12	---	---
	min	0	---	---	0.2	1510	4.0	---	---
	max	3120	---	---	1340	3290	9.4	---	---
	mean	261	---	---	280	2114	5.7	---	---
	median	180	---	---	181	1905	4.8	---	---

SC = Specific Conductance

SAR = Sodium Adsorption Ratio

cfs = cubic feet per second

Indicates exceedance of applicable Irrigation Season Standards.

uS/cm = microSiemens per centimeter

n = number of data points

---- = no data

* = MDEQ Standards do not apply.

⁺ = Mean Daily Flow is determined from Powder River above Burger Draw

Powder River at Sussex

Flow and SC were measured, and SAR was estimated in realtime at this site. SC and SAR were not collected in the winter (10/27/05 through 3/27/06). Water-quality samples were also collected. Mean daily flow values ranged from 2.0 to 736 cfs, with the mean being 102 cfs (see Fig. 4).

Mean daily SC data collected at this station ranged from 905 to 6470 $\mu\text{S}/\text{cm}$, with a mean value of 3281 $\mu\text{S}/\text{cm}$. Analytical SC values at this site ranged from 1050 to 6240 $\mu\text{S}/\text{cm}$, with the mean being 2855 $\mu\text{S}/\text{cm}$. Mean Monthly SC values for this site ranged from 1231 to 5919 $\mu\text{S}/\text{cm}$, with the mean being 3329 $\mu\text{S}/\text{cm}$. Mean daily SAR data collected at this station ranged from 0.8 to 19.2, with a mean value of 8.6. Analytical SAR values at this site ranged from 2.7 to 20.1 with the mean being 6.8. Mean Monthly SAR values for this site ranged from 2.0 to 17.4, with the mean being 8.7 (see Fig. 5).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 6-8).

Powder River below Burger Draw

Flow was measured realtime at the station “Powder River above Burger Draw”. This flow data is representative of flow at this site (see measured vs. daily mean values on Fig. 9). Water-quality samples were also collected. Mean daily flow values ranged from 1.3 to 660 cfs, with the mean being 111 cfs (see Fig. 9).

Analytical SC values at this site ranged from 1230 to 4280 $\mu\text{S}/\text{cm}$, with the mean being 2648 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 3.8 to 26.7 with the mean being 8.6 (see Fig. 10).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 11-13).

Powder River at Arvada

Flow was measured in realtime at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0 to 750 cfs, with the mean being 119 cfs (see Fig. 14).

Analytical SC values at this site ranged from 1390 to 3390 $\mu\text{S}/\text{cm}$, with the mean being 2314 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 3.6 to 11.7 with the mean being 6.2 (see Fig. 15).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 16-18).

Powder River near Moorhead

Flow and SC were measured continuously at this site; however SC was not collected in the winter (11/1/05 through 3/17/06). Water-quality samples were also collected. Mean daily flow values ranged from 0 to 1000 cfs, with the mean being 164 cfs (see Fig. 19).

Mean daily SC data collected at this station ranged from 917 to 6090 $\mu\text{S}/\text{cm}$, with a mean value of 2206 $\mu\text{S}/\text{cm}$. Analytical SC values at this site ranged from 1120 to 3660 $\mu\text{S}/\text{cm}$, with the mean being 2102 $\mu\text{S}/\text{cm}$. Mean Monthly SC values for this site ranged from 1394 to 3754 $\mu\text{S}/\text{cm}$, with the mean being 2276 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 3.1 to 9.0 with the mean being 4.6 (see Fig. 20).

Daily mean and analytical SC values were above the EC instantaneous maximum standard from 6/25/06-6/28/06 and from 7/1/06 - 9/17/06. Mean monthly SC values were in excess of the mean monthly EC standard during March and June - September. Analytical SAR values were above the instantaneous maximum standard from 6/27/06 - 7/27/06 (see Fig. 20).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 21-23).

Powder River near Locate

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0 to 3120 cfs, with the mean being 261 cfs (see Fig. 24).

Analytical SC values at this site ranged from 1510 to 3290 $\mu\text{S}/\text{cm}$, with the mean being 2114 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 4.0 to 9.4 with the mean being 5.7 (see Fig. 25).

Analytical SC values were above the EC instantaneous maximum standard for 3 of the 12 samples collected. Analytical SAR values were above the instantaneous maximum standard for 3 of the 12 samples collected (see Fig. 25).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 26-28).

Tributary Sites

**Table 5: Water Year 2006 Summary Statistics for Tributary Sites
in the Powder River Watershed**

		Mean Daily			Analytical			Mean Monthly	
		Flow (cfs)	SC (uS/cm)	SAR	Flow (cfs)	SC (uS/cm)	SAR	SC (uS/cm)	SAR
Crazy Woman, near Arvada, WY*	n	365	182	173	21	21	21	8	8
	min	0	1210	1.4	0.01	1130	1.5	1567	1.8
	max	42	4950	5.5	24	3660	5.7	3786	4.3
	mean	8.4	2144	2.4	10	1950	2.5	2240	2.6
	median	8.0	2005	2.2	9	1670	2.0	1887	2.2
Clear Creek near Arvada, WY*	n	365	365	363	25	25	24	12	12
	min	0	412	0.6	0.2	523	0.7	678	0.8
	max	344	2070	2.2	174	2020	2.4	1902	2.1
	mean	64	1190	1.4	60	1221	1.3	1190	1.4
	median	72	1060	1.2	71	1060	1.2	1057	1.2
Little Powder River above Dry Creek near Weston, WY*	n	365	---	---	13	13	12	---	---
	min	0	---	---	0.02	500	3.0	---	---
	max	837	---	---	15	4540	8.9	---	---
	mean	9.6	---	---	3.3	2976	6.6	---	---
	median	1.7	---	---	1.2	3380	7.4	---	---
Little Powder River near Broadus, MT	n	---	---	---	12	12	12	---	---
	min	---	---	---	1.4	500	1.6	---	---
	max	---	---	---	77	3020	17.5	---	---
	mean	---	---	---	15.4	2187	7.8	---	---
	median	---	---	---	9.6	2295	7.3	---	---

SC = Specific Conductance

SAR = Sodium Adsorption Ratio

cfs = cubic feet per second

Indicates exceedance of applicable Irrigation Season Standards.

uS/cm = microSiemens per centimeter

n = number of data points

---- = no data

* = MDEQ Standards do not apply.

Crazy Woman Creek near Arvada

Flow and SC were measured, and SAR was estimated in realtime at this site. SC and SAR were not collected in the winter (11/22/05 through 3/22/06). Water-quality samples were also collected. Mean daily flow values ranged from 0 to 42 cfs, with the mean being 8.4 cfs (see Fig. 29).

Mean daily SC data collected at this station ranged from 1210 to 4950 $\mu\text{S}/\text{cm}$, with a mean value of 2144 $\mu\text{S}/\text{cm}$. Analytical SC values at this site ranged from 1130 to 3660 $\mu\text{S}/\text{cm}$, with the mean being 1950 $\mu\text{S}/\text{cm}$. Mean Monthly SC values for this site ranged from 1567 to 3786 $\mu\text{S}/\text{cm}$, with the mean being 2240 $\mu\text{S}/\text{cm}$. Mean daily SAR data collected at this station ranged from 1.4 to 5.5, with a mean value of 2.4. Analytical SAR values at this site ranged from 1.5 to 5.7 with the mean being 2.5. Mean Monthly SAR values for this site ranged from 1.8 to 4.3, with the mean being 2.6 (see Fig. 30).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 31-33).

Clear Creek near Arvada

Flow and SC were measured, and SAR was estimated in realtime at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0 to 344 cfs, with the mean being 64 cfs (see Fig. 34).

Mean daily SC data collected at this station ranged from 412 to 2070 $\mu\text{S}/\text{cm}$, with a mean value of 1190 $\mu\text{S}/\text{cm}$. Analytical SC values at this site ranged from 523 to 2020 $\mu\text{S}/\text{cm}$, with the mean being 1221 $\mu\text{S}/\text{cm}$. Mean Monthly SC values for this site ranged from 678 to 1902 $\mu\text{S}/\text{cm}$, with the mean being 1190 $\mu\text{S}/\text{cm}$. Mean daily SAR data collected at this station ranged from 0.6 to 2.2, with a mean value of 1.4. Analytical SAR values at this site ranged from 0.7 to 2.4 with the mean being 1.3. Mean Monthly SAR values for this site ranged from 0.9 to 2.1, with the mean being 1.4 (see Fig. 35).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 36-38).

Little Powder near Weston

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0 to 837 cfs, with the mean being 9.6 cfs (see Fig. 39).

Analytical SC values at this site ranged from 500 to 4540 $\mu\text{S}/\text{cm}$, with the mean being 2976 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 3.0 to 8.9 with the mean being 6.6 (see Fig. 40).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 41-43).

Little Powder near Broadus

Flow was measured during sampling events at this site. Water-quality samples were also collected. Measured flow values ranged from 1.4 to 77 cfs, with the mean being 15.4 cfs (see Fig. 44).

Analytical SC values at this site ranged from 500 to 3020 $\mu\text{S}/\text{cm}$, with the mean being 2187 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 1.6 to 17.5 with the mean being 7.8 (see Fig. 45).

Recorded SC values were above the EC instantaneous maximum standard for 4 of the 12 samples collected. SAR values were in excess of the instantaneous maximum standard for 5 of the 12 samples collected (see Fig. 45).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 46-48).

Conclusions

During Water Year 2006 (October 2005-September 2006) flows within the Powder River watershed were less than historical averages. EC and SAR are correlated with flow so an evaluation of EC and SAR must also take flow into account.

A comparison to the MDEQ surface water standards for EC and SAR showed that these standards are exceeded part of the time for every parameter at every station to which they apply.

A statistical trend analysis was not conducted for this report; however it is expected that the USGS will soon be publishing a trend study which includes the Powder River (Clark, pers. com). Visual inspection of the SC vs. Flow, SAR vs. Flow, and SC vs. SAR graphs does not indicate noticeable deviation from historical trends.

References

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Reviewers

Jim Lloyd

MDEQ, Helena, MT

Melanie Clark

USGS, Cheyenne, WY

David Nimick

USGS, Helena, MT

Figures

Figure 1: Comparison of Crop Yield to SC (Salinity) and Recorded 2006 SC Values in the Powder River Watershed

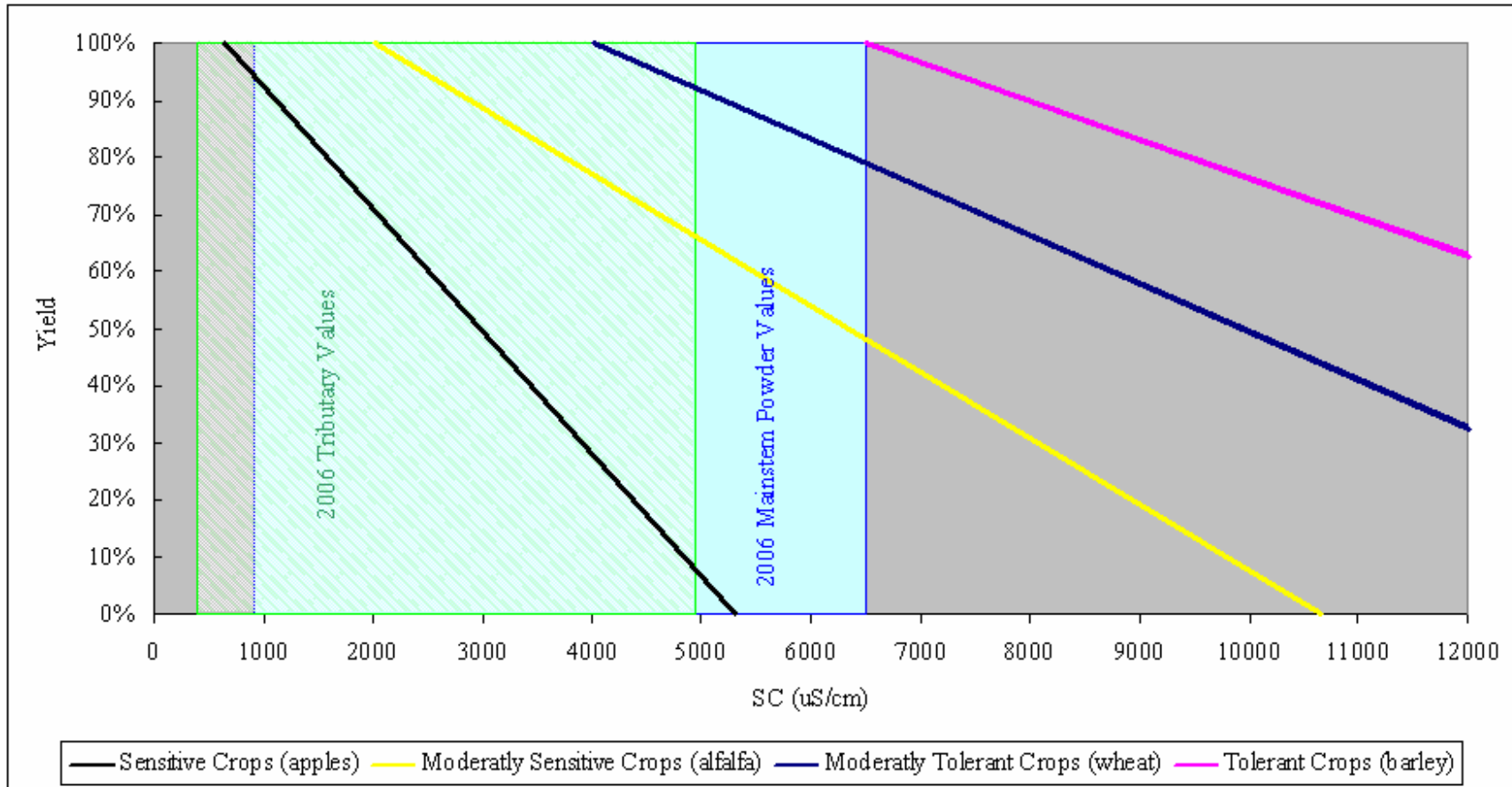


Figure 1 shows the range of SC values recorded during water year 2006 compared to yield vs. salinity curves for representative crops (Ayers and Westcott, 1985). Note that yield comparisons are made to that which would be attained using low salinity irrigation water, and assumes that all other factors (including water availability) are equal. Mainstem values ranged from 905 to 6470 uS/cm. Tributary values ranged from 412 to 4950 uS/cm.

Figure 2: Comparison of Infiltration Criteria and Recorded 2006 SC and SAR Values in the Powder River Watershed

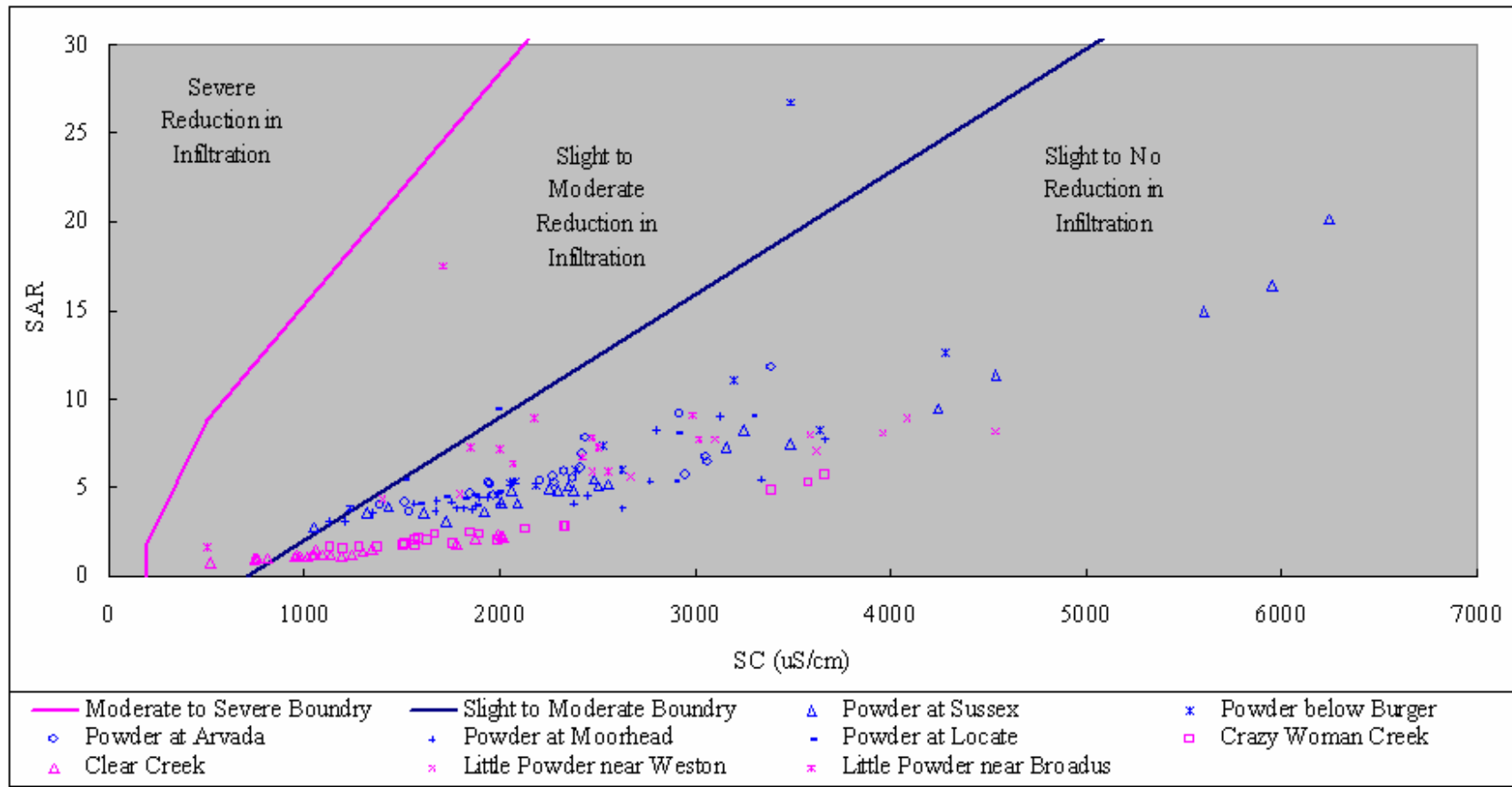


Figure 2 shows water quality data from water year 2006 in the Powder River Watershed compared to the infiltration criteria developed by Hanson et al. (1999). Most values fall within the Slight to No reduction in infiltration field; however particular samples from the Powder River at Sussex, Powder River below Burger Draw, Powder River at Moorhead, Powder River at Locate, Clear Creek, and the Little Powder near Broadus fall within the Slight to Moderate reduction field.

Figure 3: Comparison of Irrigation Water Classification and Recorded 2006 SC and SAR Values in the Powder River Watershed

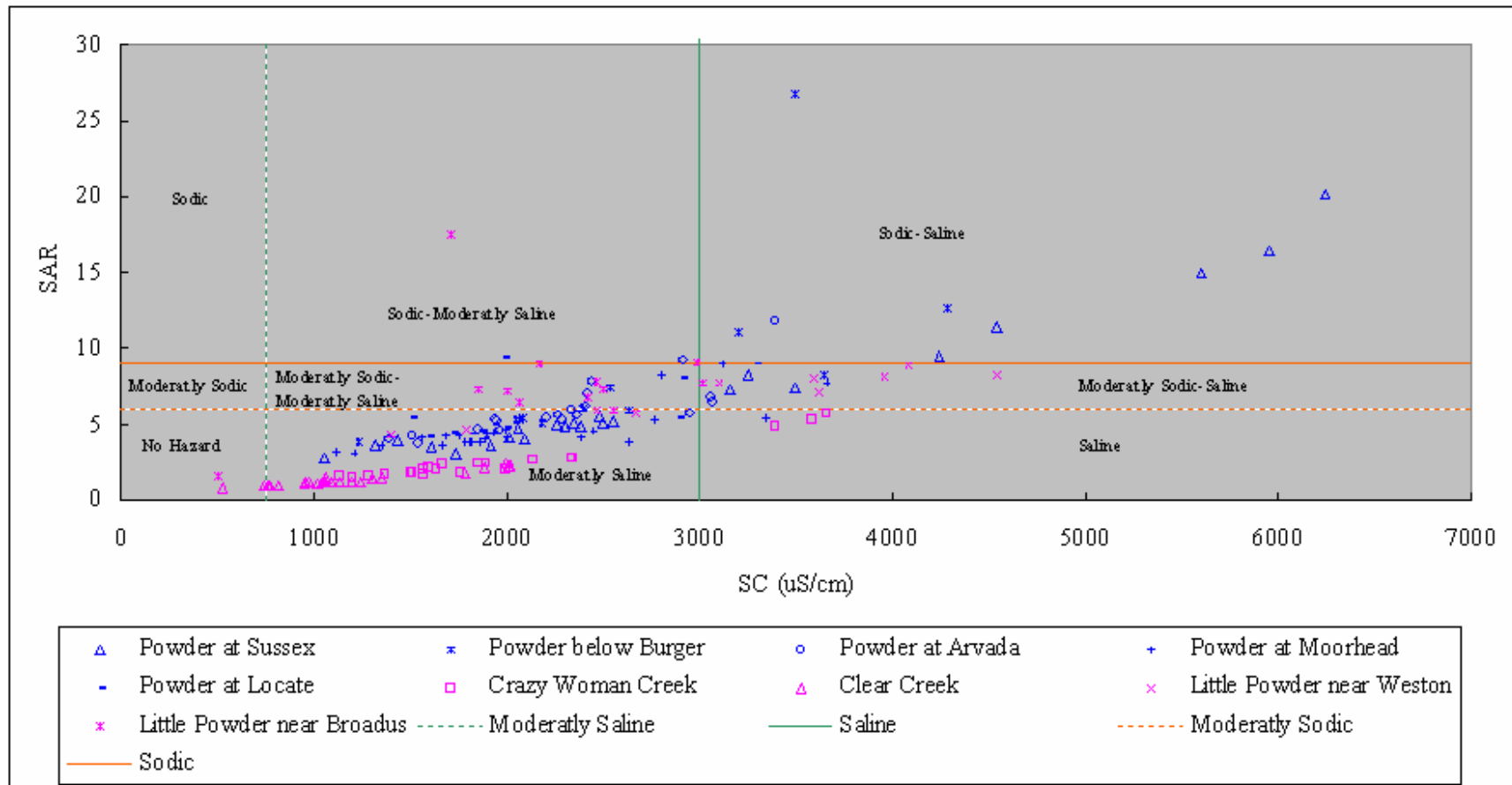


Figure 3 shows water quality data from water year 2006 in the Powder River Watershed compared to irrigation water classifications (Western Fertilizer Handbook, 1995). Most values fall within the Moderately Saline field; however samples also fall within the No Hazard, Saline, Moderately Sodic – Moderately Saline, Sodic – Moderately Saline, Moderately Sodic- Saline, and Sodic – Saline fields.

Figure 4: Powder River at Sussex, WY

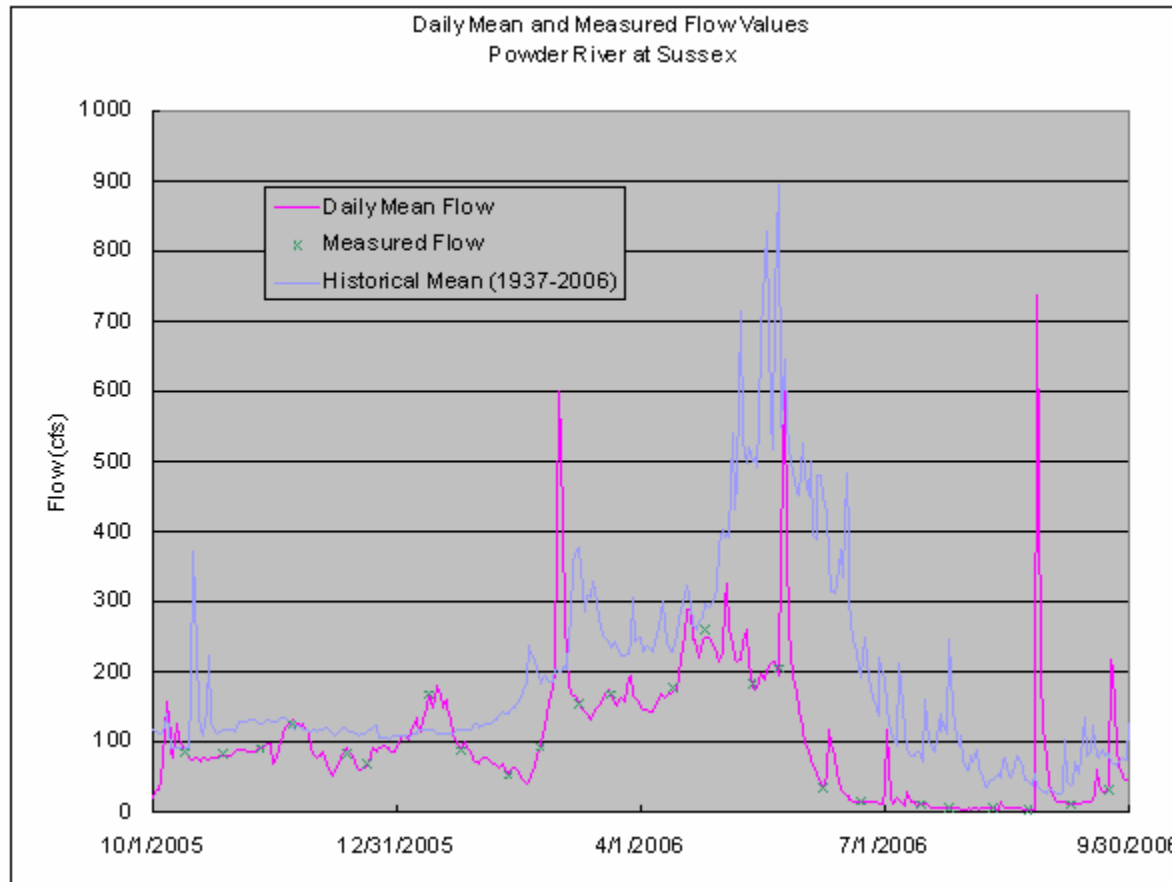


Figure 4 shows mean daily and field measurements of flow in a time series plot for water year 2006 for the Powder River at Sussex. Flow values ranged from 2.0 to 736 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 5: Powder River at Sussex, WY

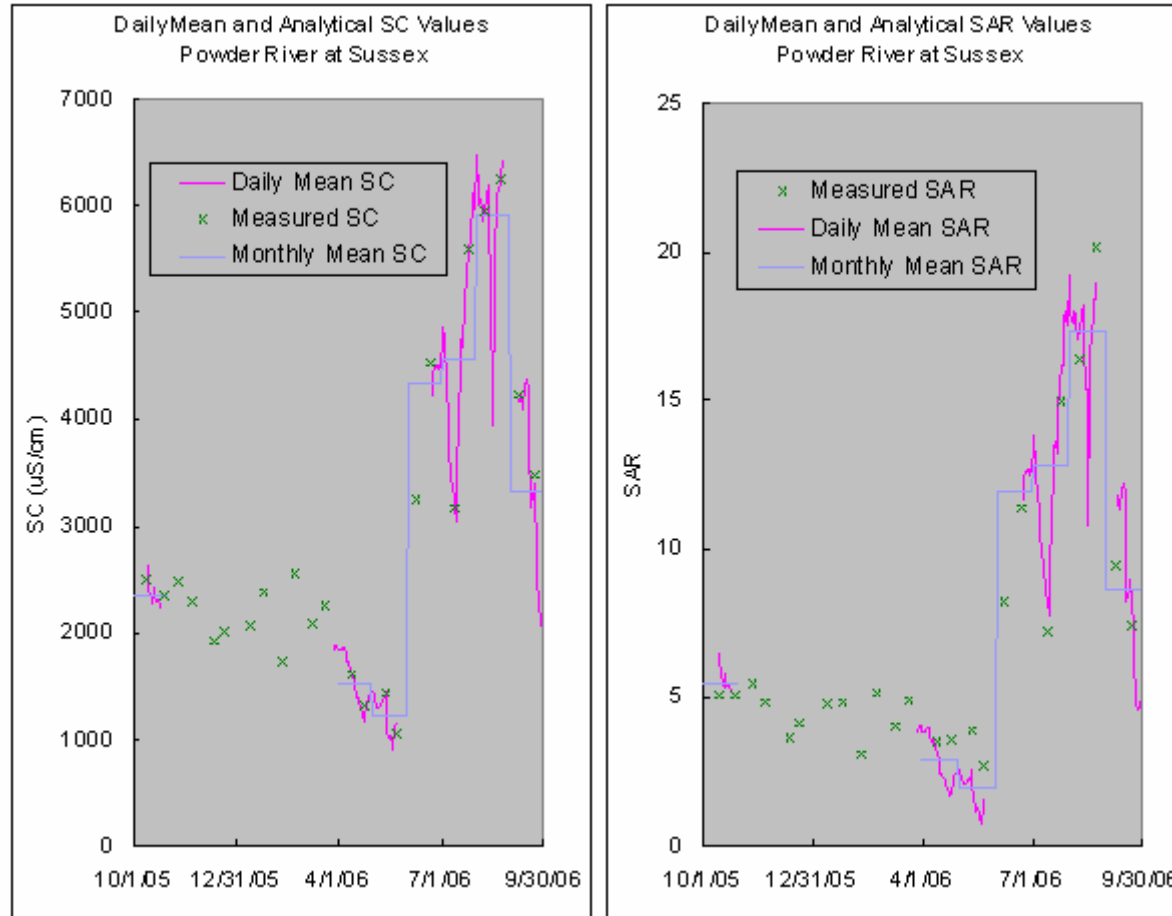


Figure 5 shows analytical SC values (A) and analytical SAR values (B) in time series plots for water year 2006 for the Powder River at Sussex. Mean Monthly SC and SAR values are also shown. SC values ranged from 905 to 6470 uS/cm. SAR values ranged from 0.78 to 20.1.

Figure 6: Powder River at Sussex, WY

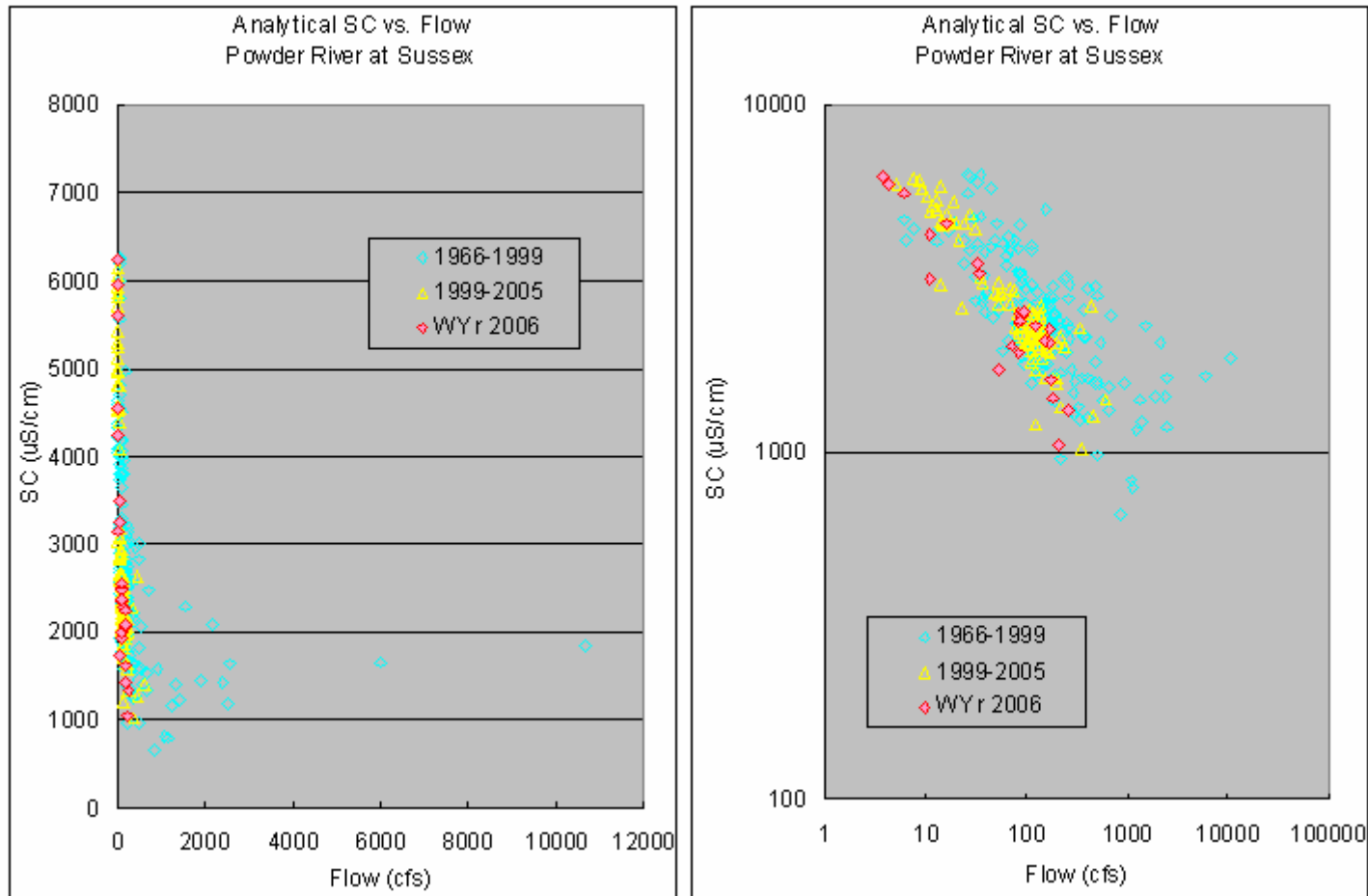


Figure 6 shows analytical SC vs. Flow data for water year 2006 for the Powder River at Sussex. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 7: Powder River at Sussex, WY

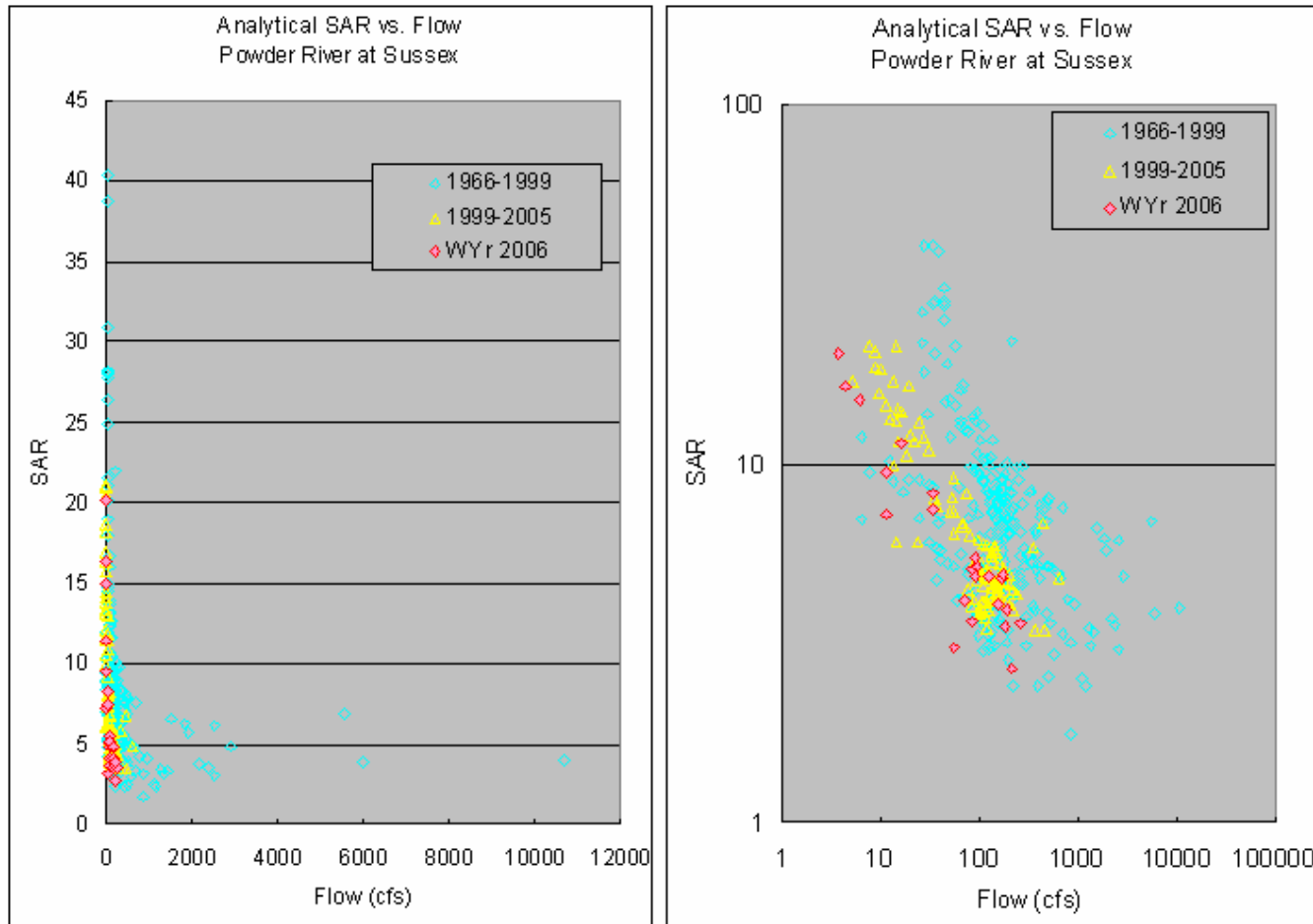


Figure 7 shows analytical SAR vs. Flow data for water year 2006 for the Powder River at Sussex. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 8: Powder River at Sussex, WY

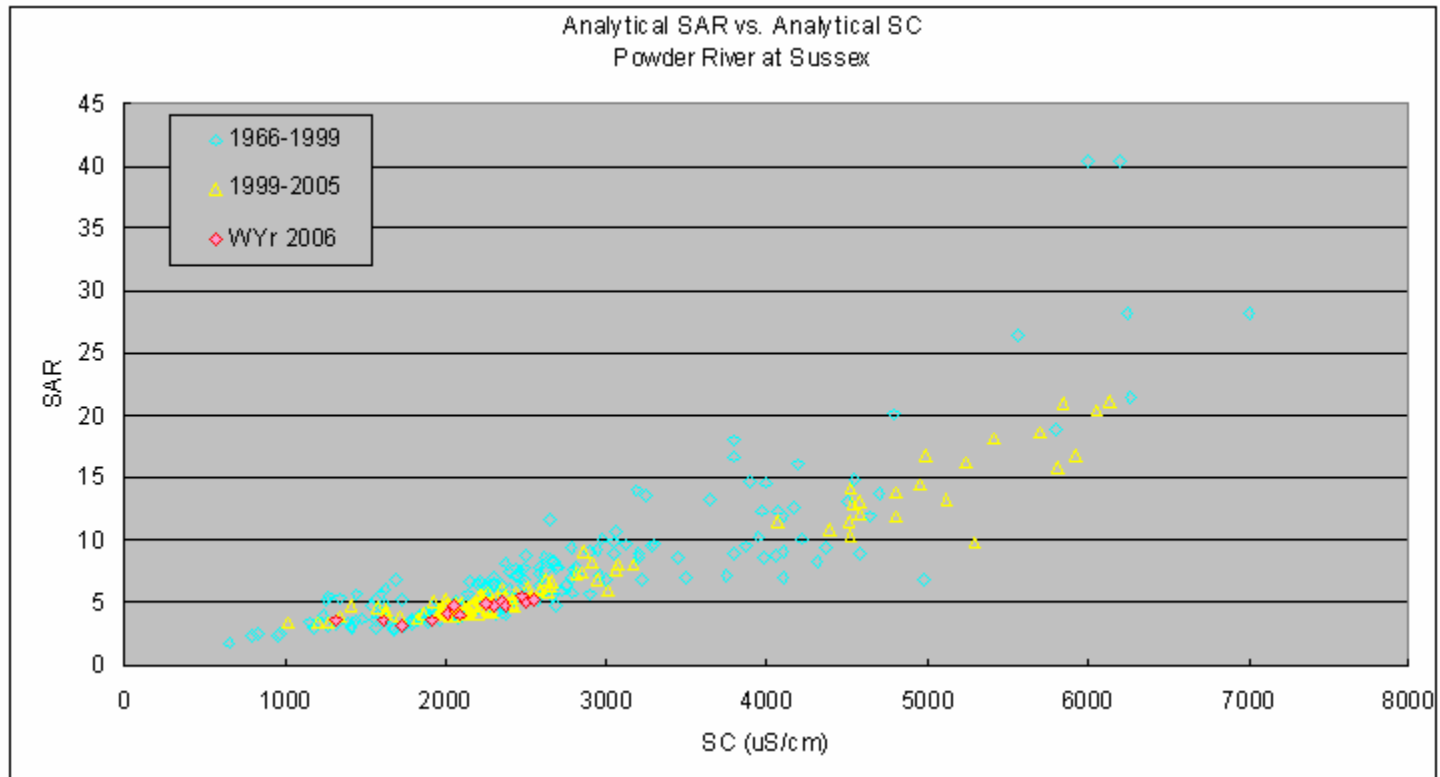


Figure 8 shows analytical SAR vs. analytical SC data for water year 2006 for the Powder River at Sussex. Historical SAR vs. SC data are also shown to place the data in context.

Figure 9: Powder River below Burger Draw, near Buffalo, WY

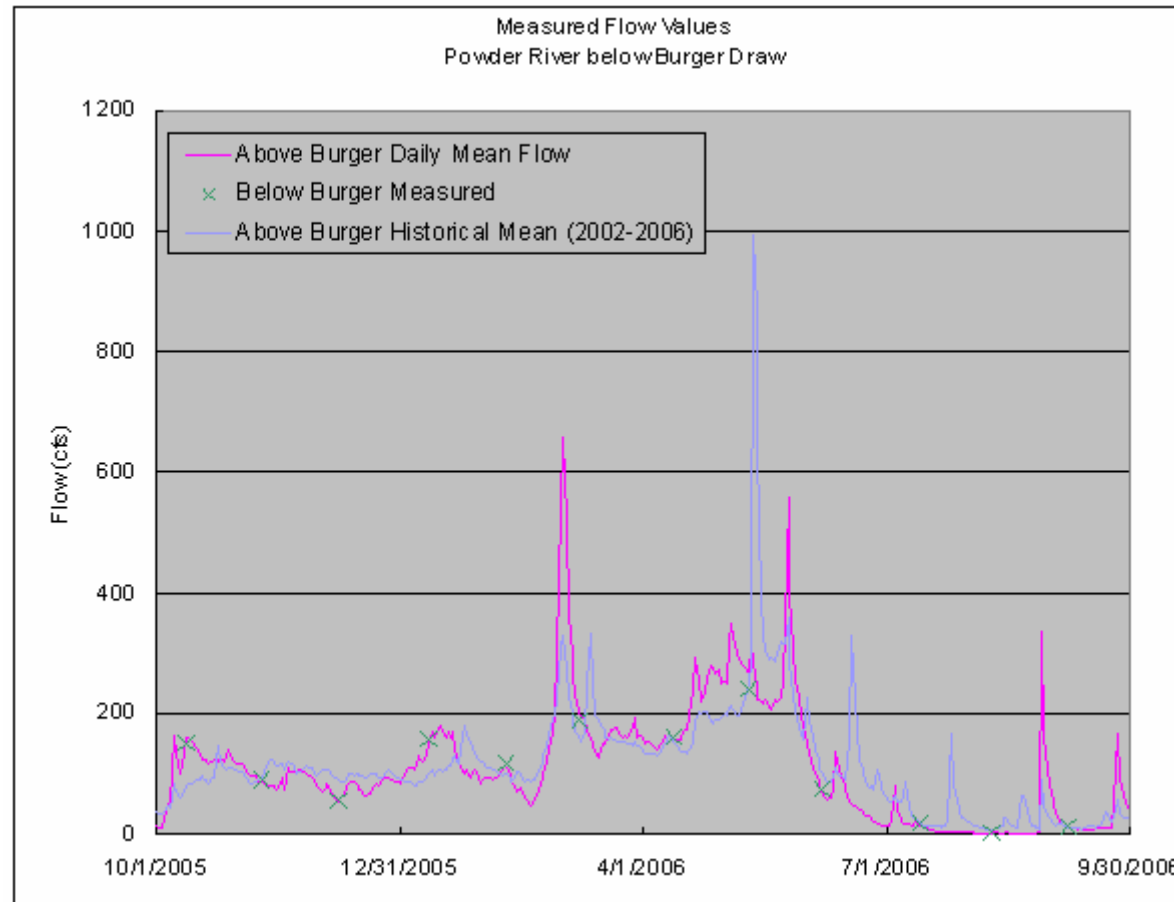


Figure 9 shows field measurements of flow in a time series plot for water year 2006 for the Powder River above and below Burger Draw. Recorded flow values ranged from 1.3 to 660 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 10: Powder River below Burger Draw, near Buffalo, WY

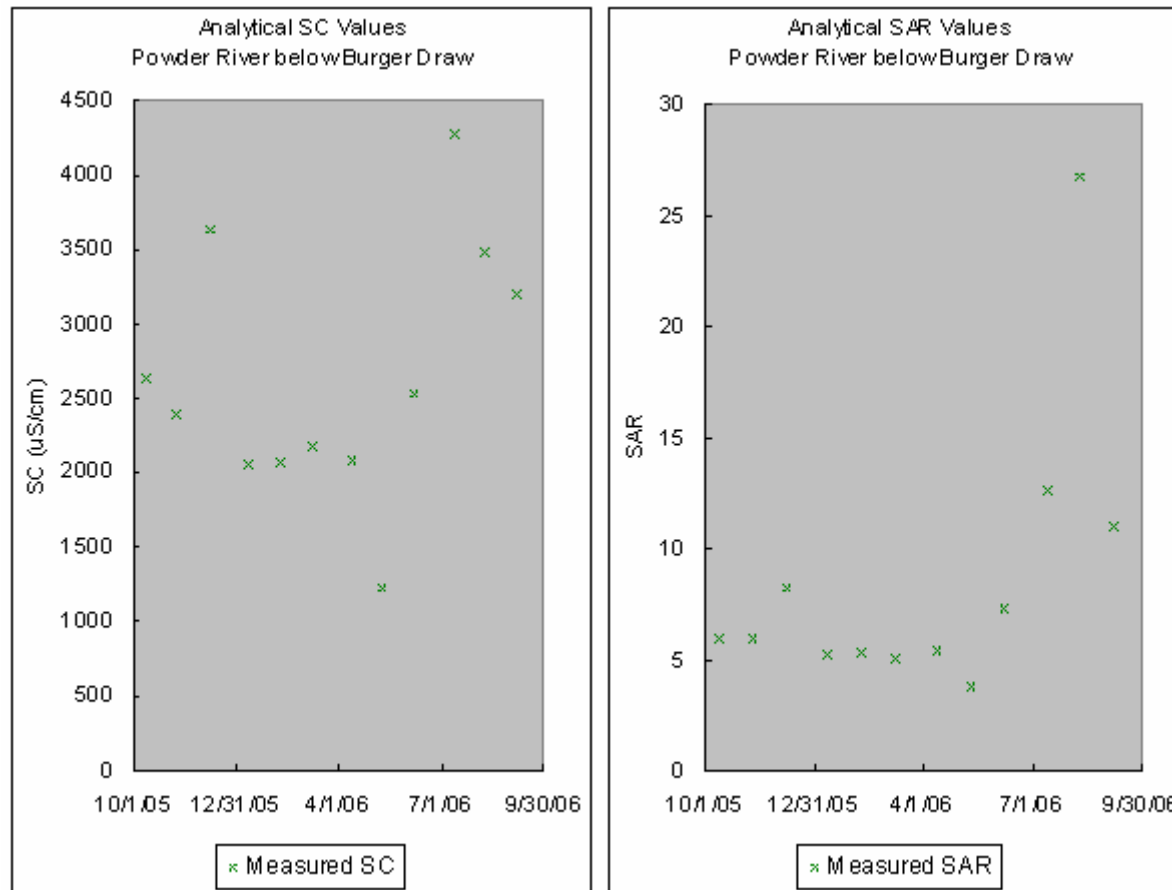


Figure 10 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2006 for the Powder River below Burger Draw. SC values ranged from 1230 to 4280 uS/cm. SAR values ranged from 3.77 to 26.7.

Figure 11: Powder River below Burger Draw, near Buffalo, WY

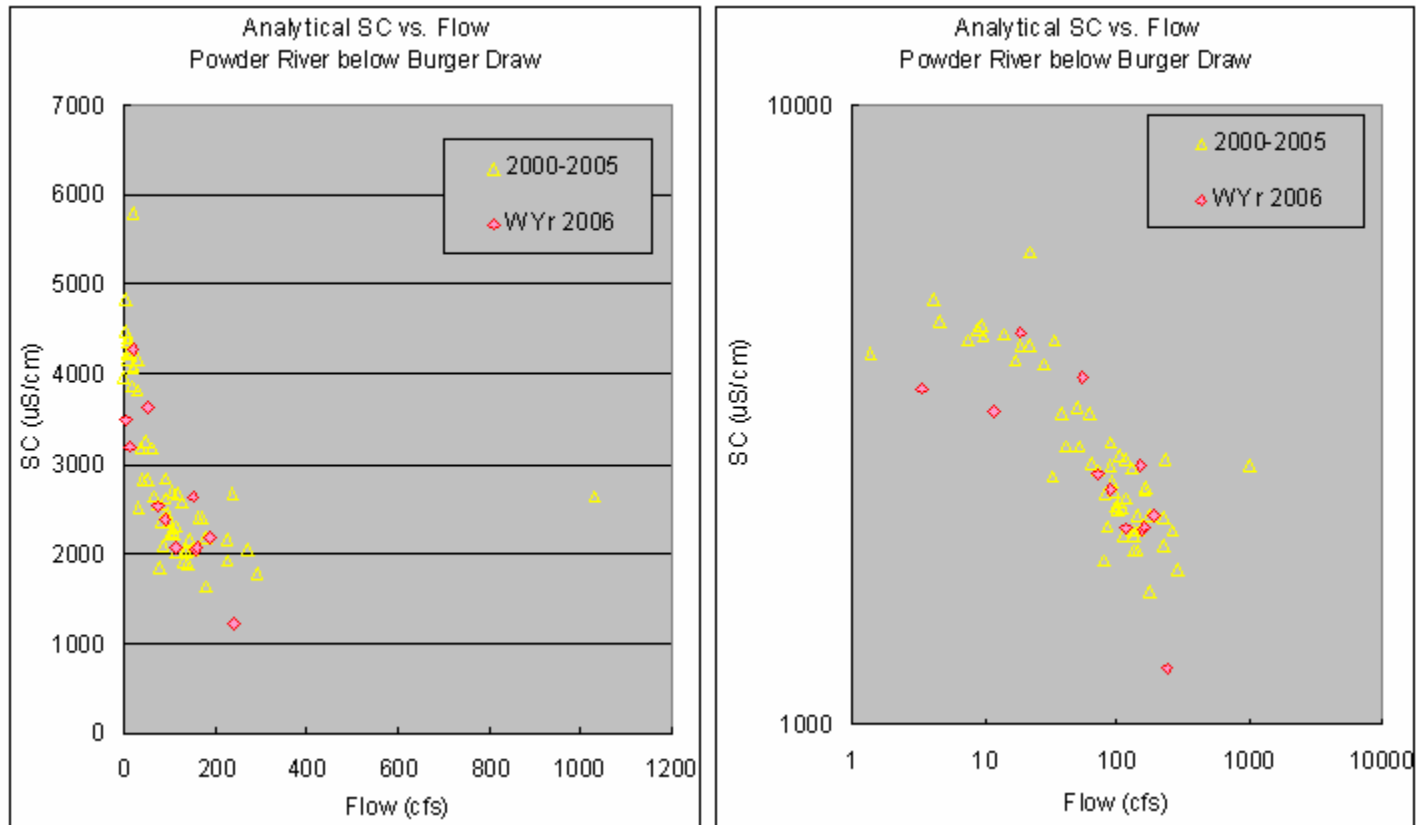


Figure 11 shows analytical SC vs. Flow data for water year 2006 for the Powder River below Burger Draw. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 12: Powder River below Burger Draw, near Buffalo, WY

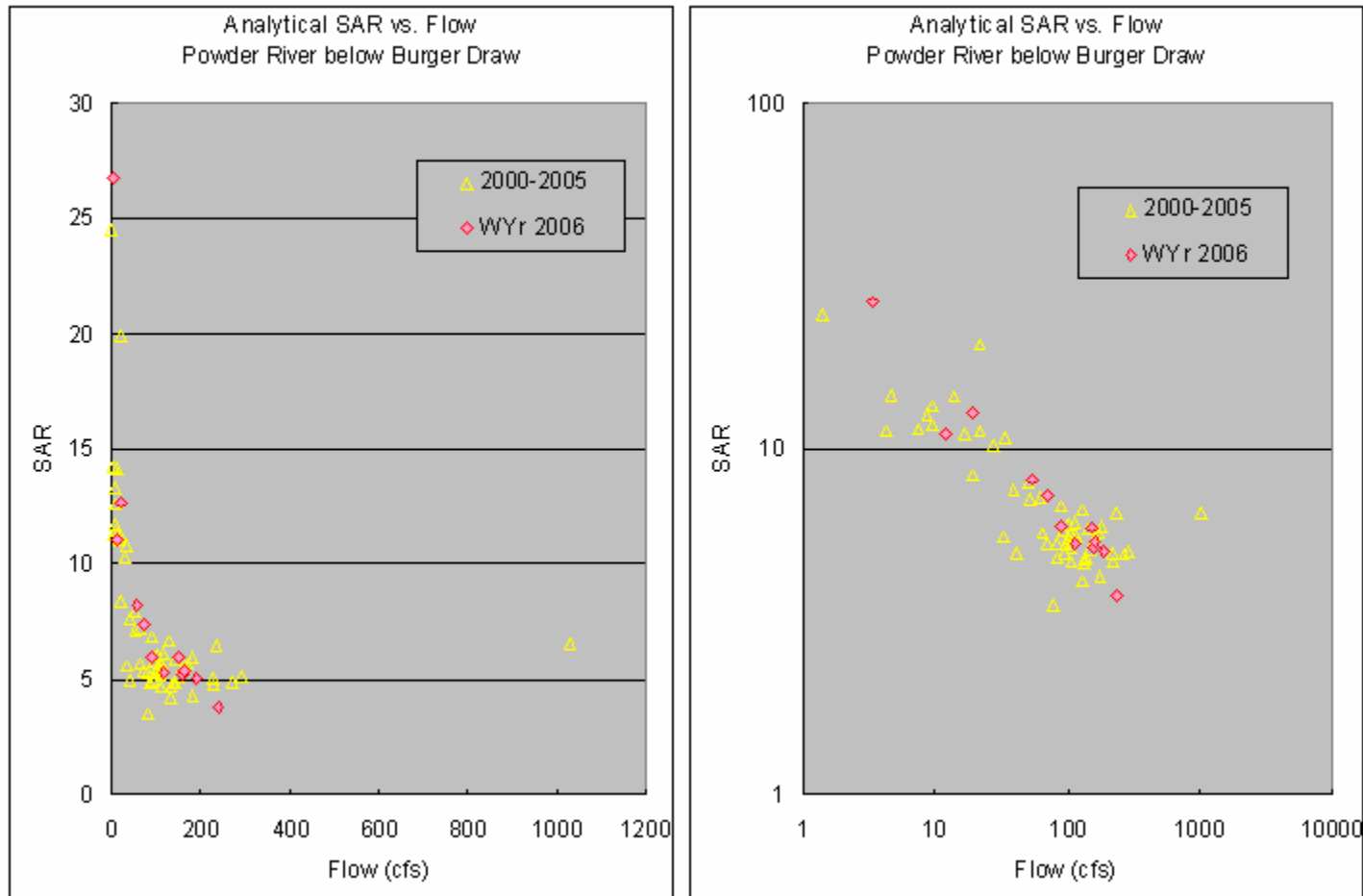


Figure 12 shows analytical SAR vs. Flow data for water year 2006 for the Powder River below Burger Draw. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 13: Powder River below Burger Draw, near Buffalo, WY

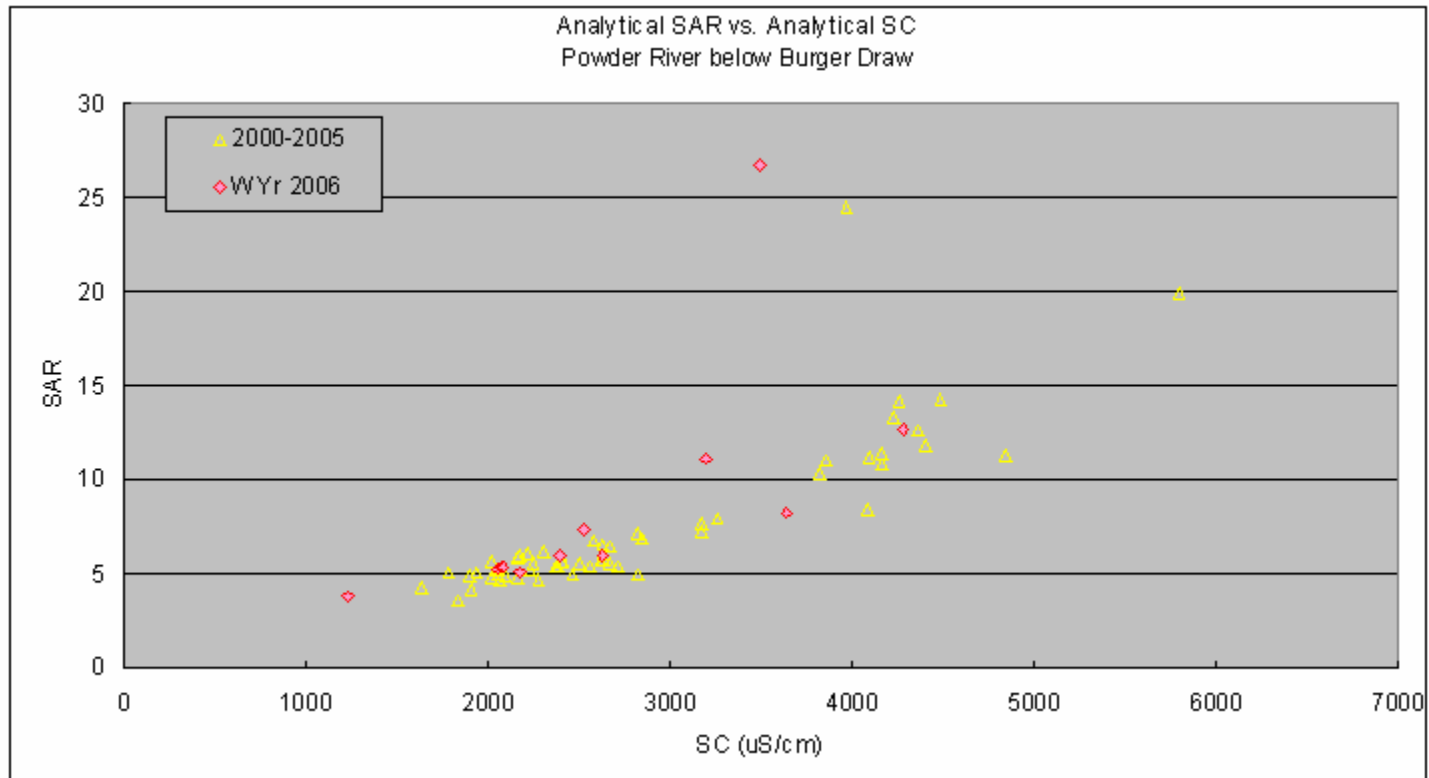


Figure 13 shows analytical SAR vs. analytical SC data for water year 2006 for the Powder River below Burger Draw. Historical SAR vs. SC data are also shown to place the data in context.

Figure 14: Powder River at Arvada, WY

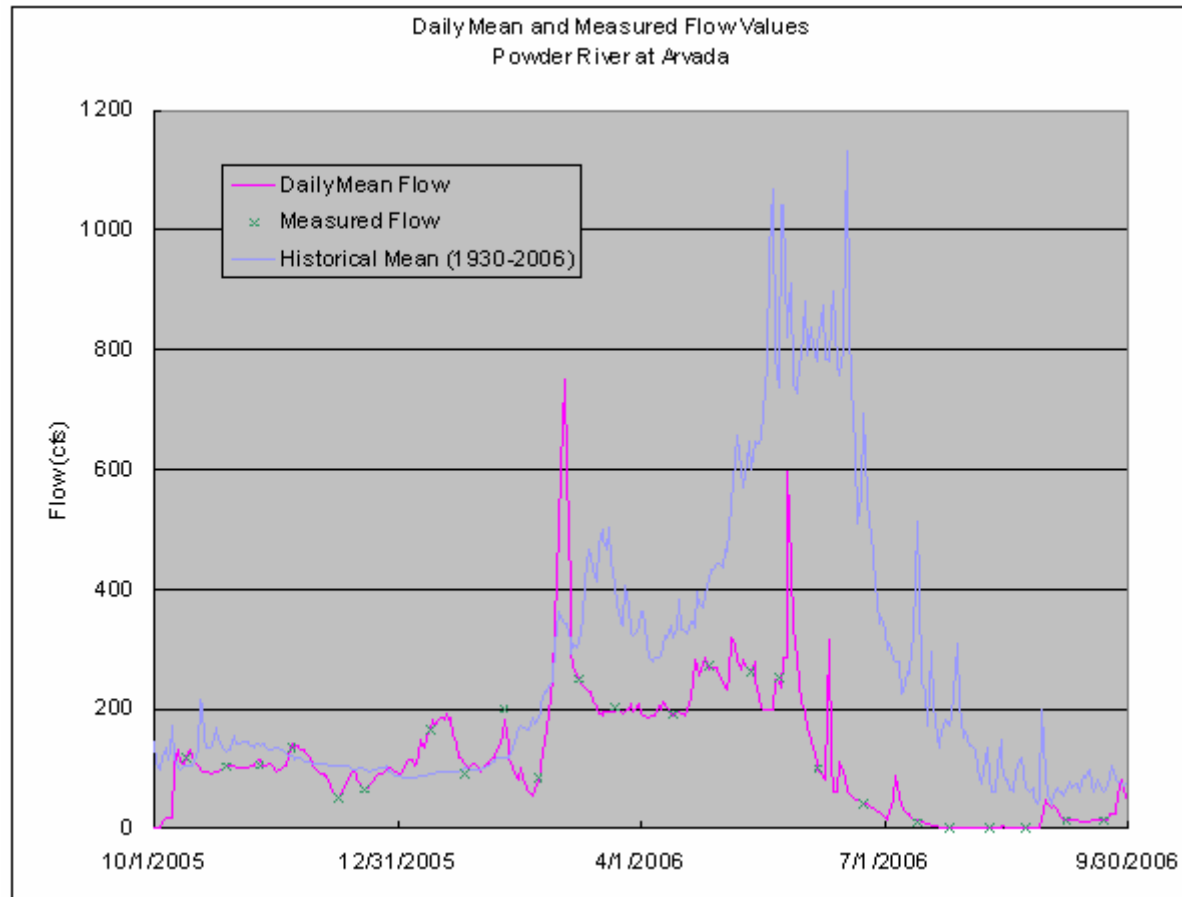


Figure 14 shows mean daily and field measurements of flow in a time series plot for water year 2006 for the Powder River at Arvada. Mean daily flow values ranged from 0 to 750 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 15: Powder River at Arvada, WY

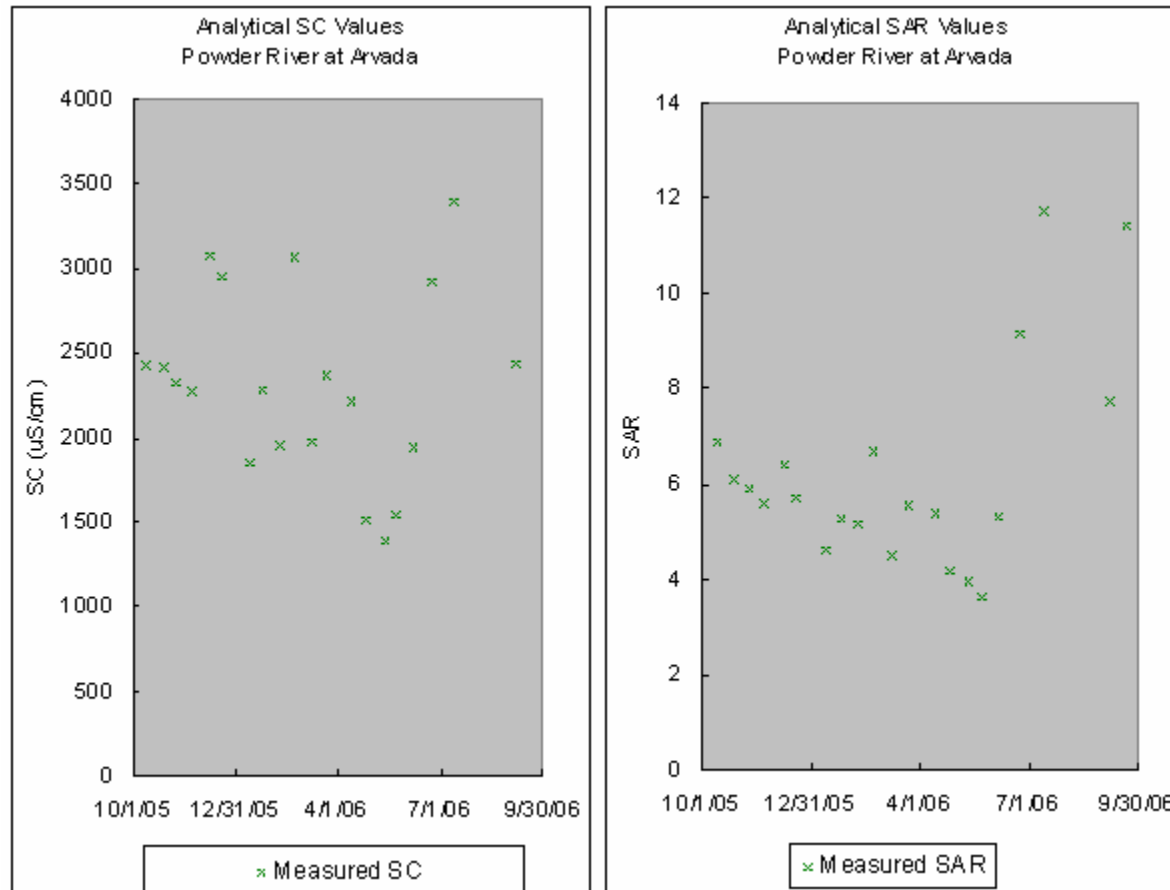


Figure 15 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2006 for the Powder River at Arvada. SC values ranged from 1390 to 3390 uS/cm. SAR values ranged from 3.64 to 11.7.

Figure 16: Powder River at Arvada, WY

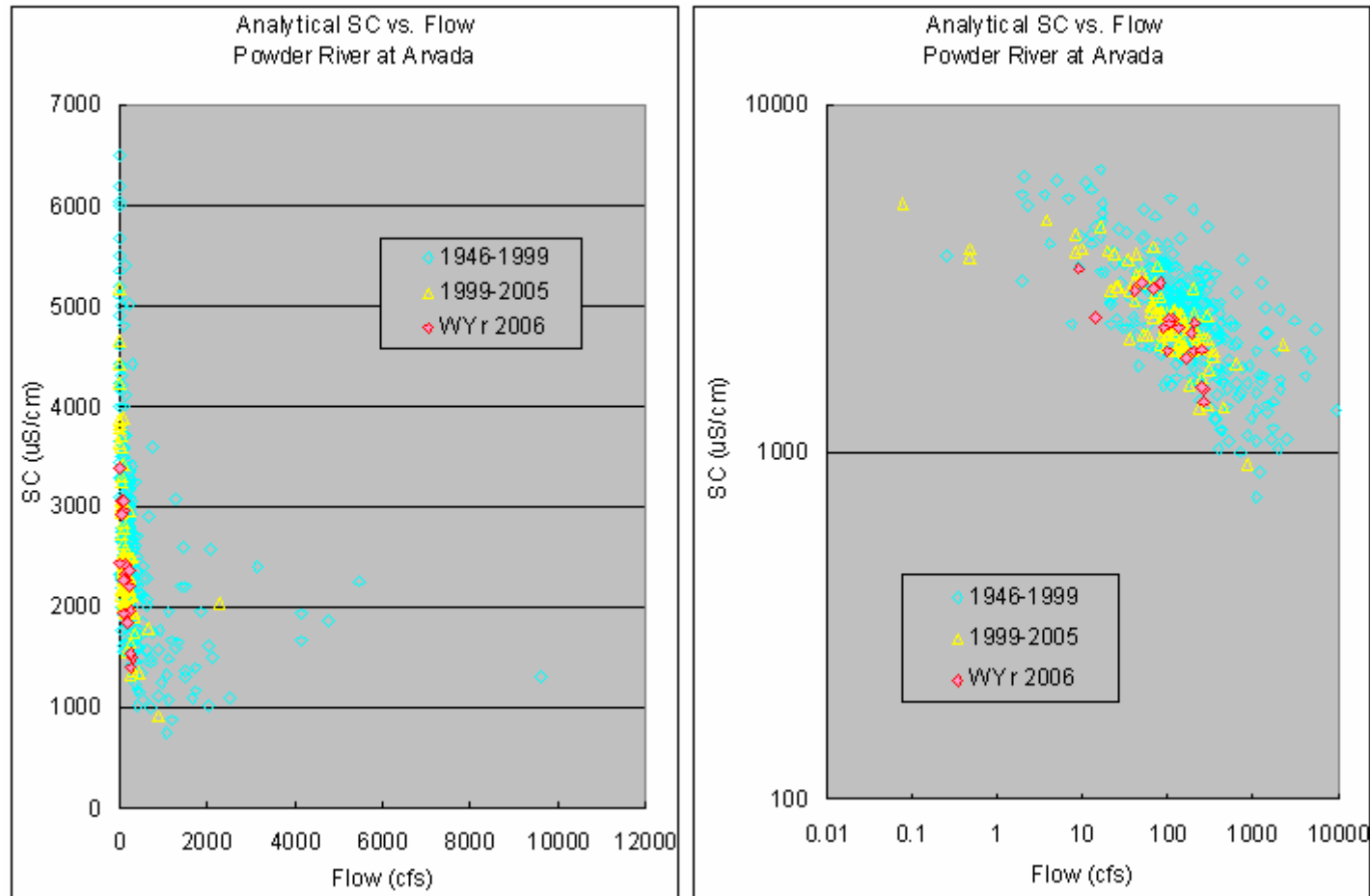


Figure 16 shows analytical SC vs. Flow data for water year 2006 for the Powder River at Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 17: Powder River at Arvada, WY

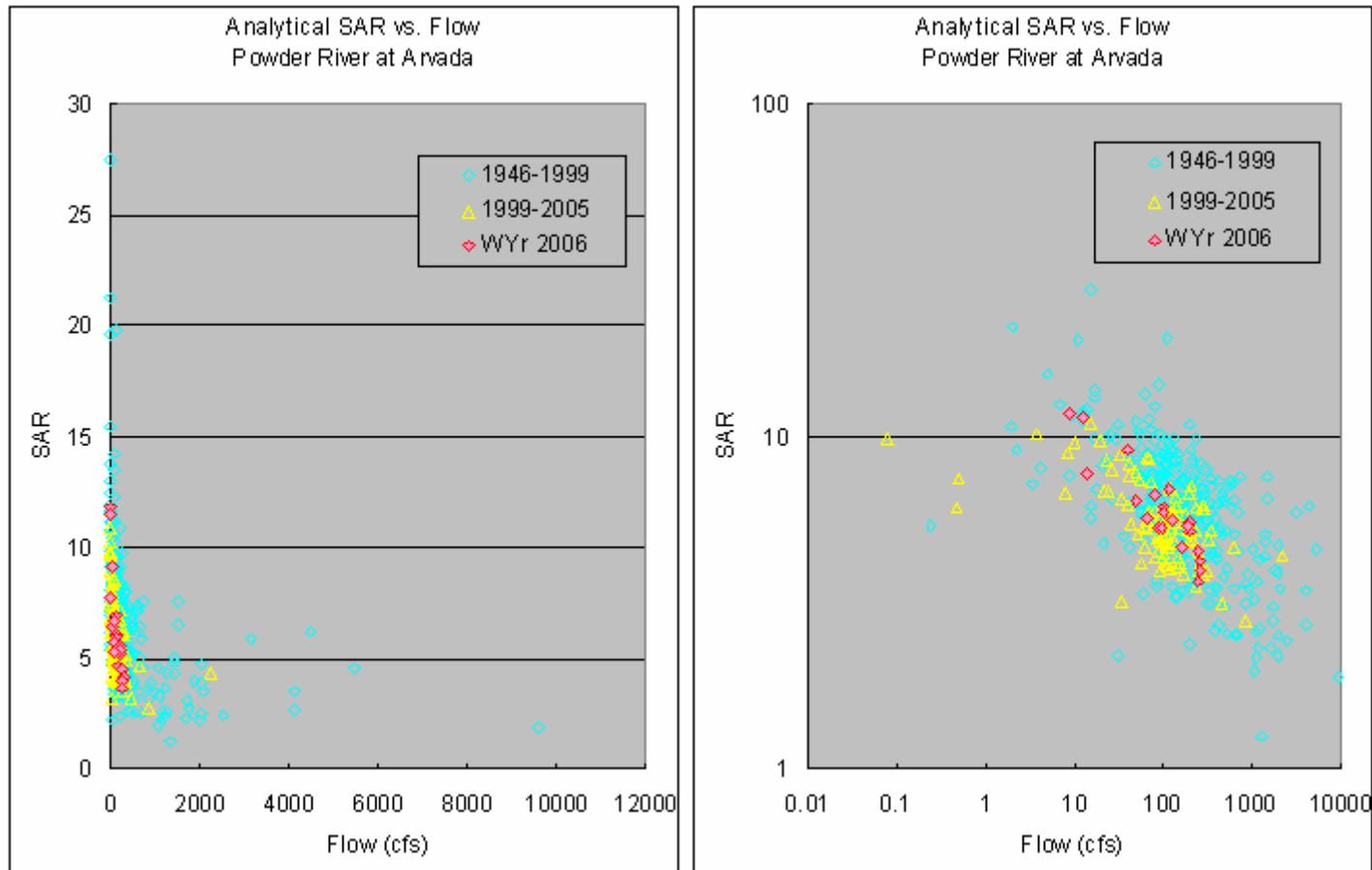


Figure 17 shows analytical SAR vs. Flow data for water year 2006 for the Powder River at Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 18: Powder River at Arvada, WY

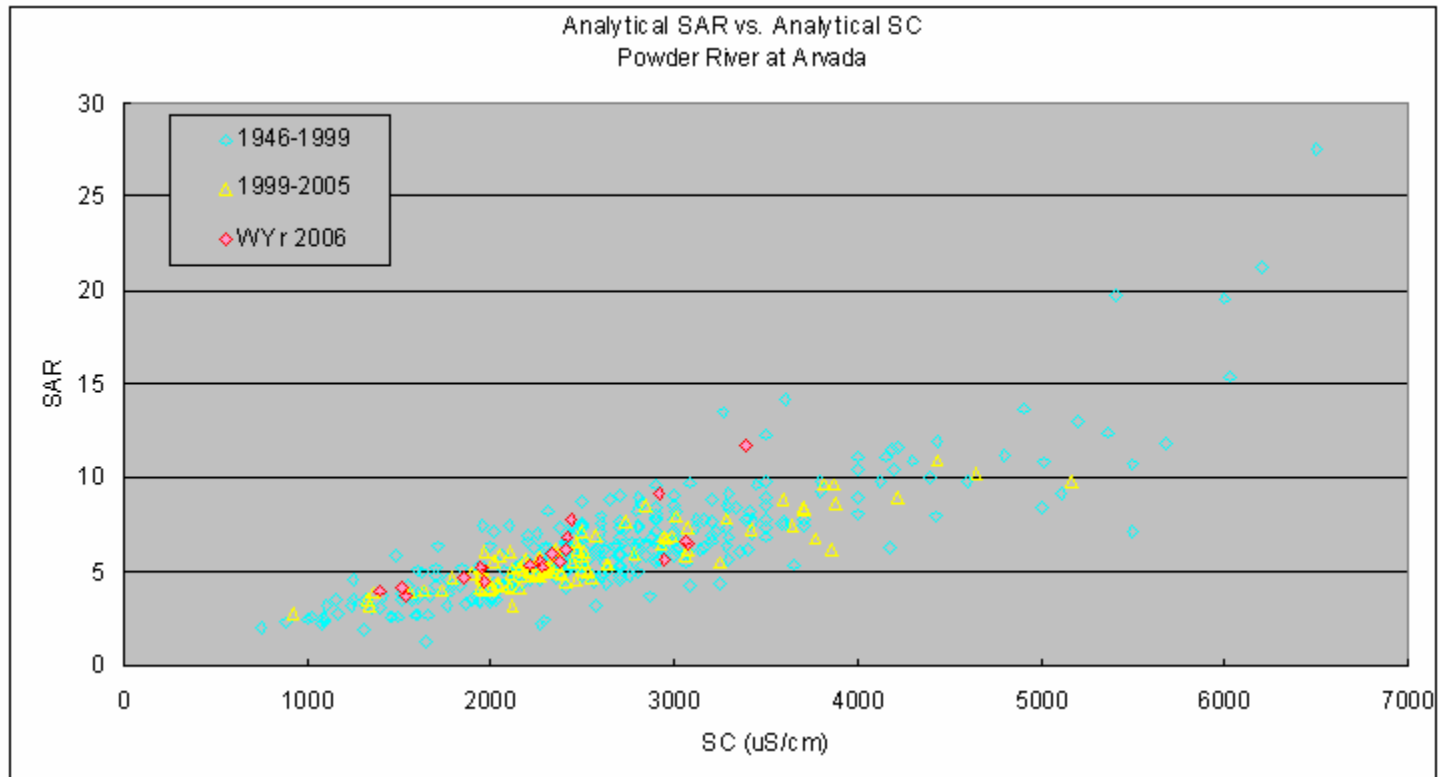


Figure 18 shows analytical SAR vs. analytical SC data for water year 2006 for the Powder River at Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 19: Powder River at Moorhead, MT

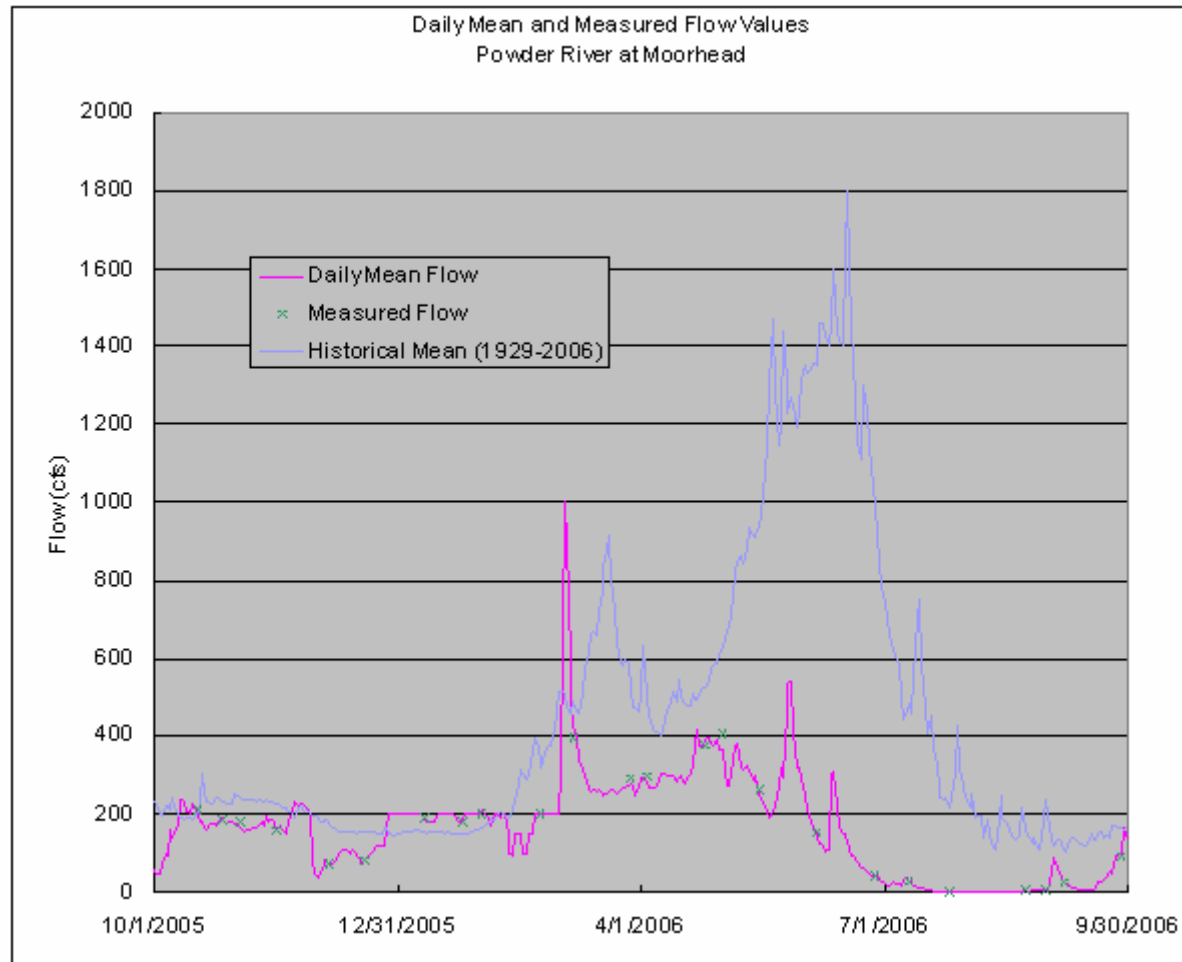


Figure 19 shows mean daily and field measurements of flow in a time series plot for water year 2006 for the Powder River at Moorhead. Mean daily flow values ranged from 0 to 1000 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 20: Powder River at Moorhead, MT

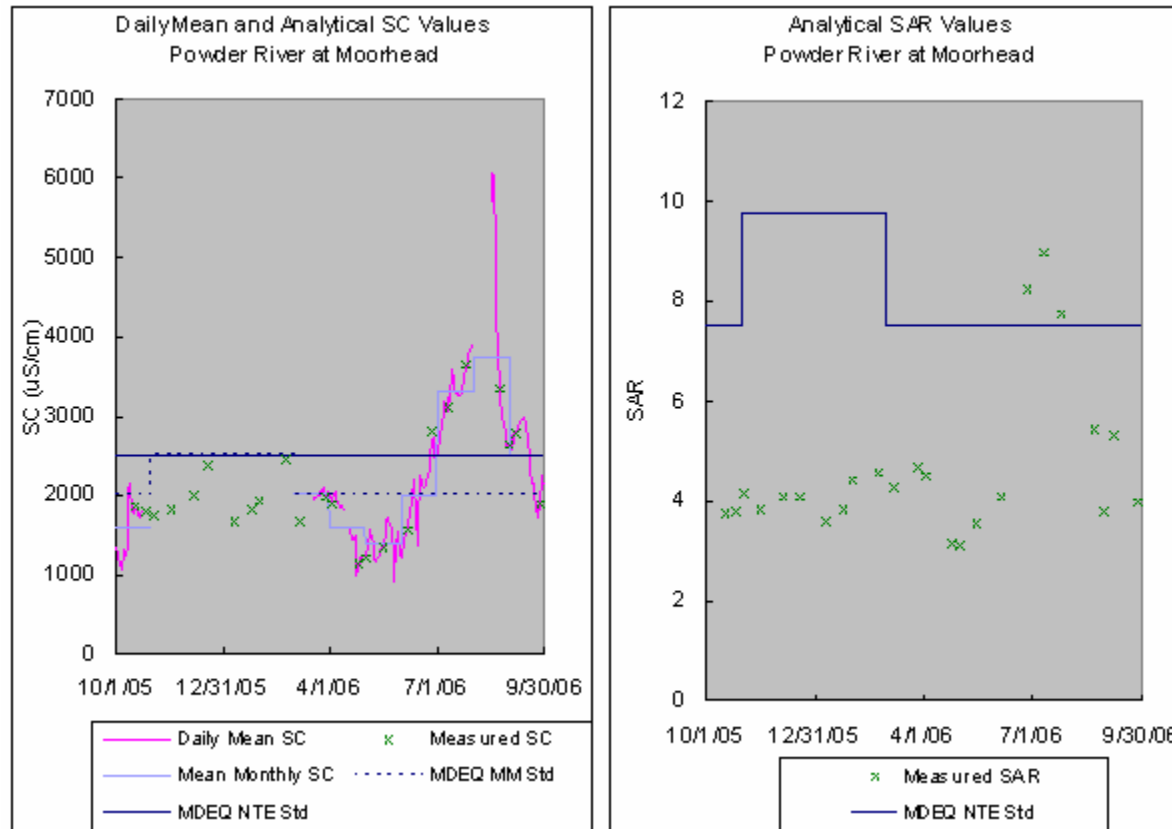


Figure 20 shows analytical and mean daily SC values (A) and analytical SAR values (B) values in time series plots for water year 2006 for the Powder River at Moorhead. Mean Monthly SC values are also shown. SC values ranged from 917 to 6090 uS/cm. SAR values ranged from 3.1 to 9.0. MDEQ standards are also displayed for comparison.

Figure 21: Powder River at Moorhead, MT

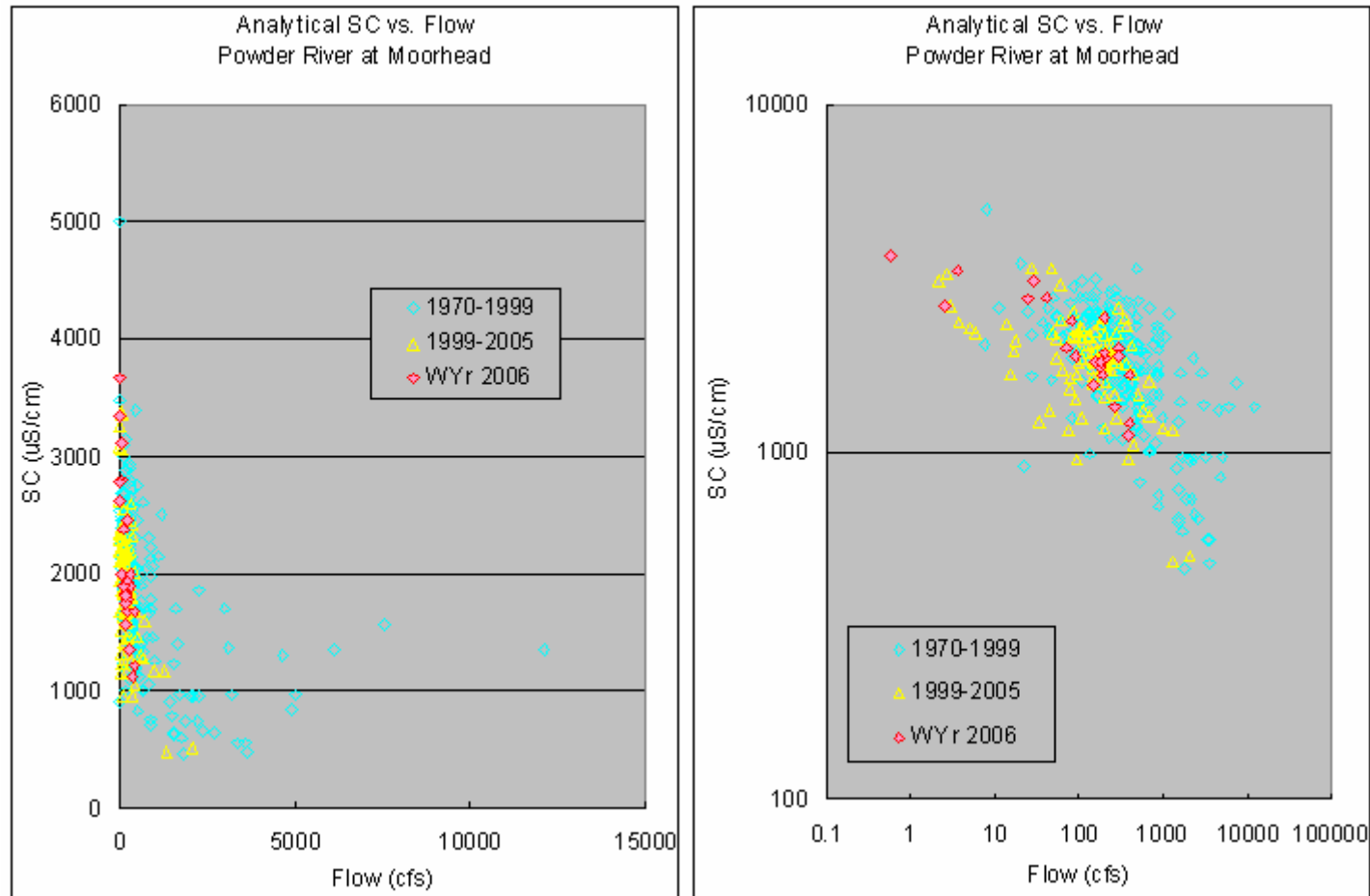


Figure 21 shows analytical SC vs. Flow data for water year 2006 for the Powder River at Moorhead. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 22: Powder River at Moorhead, MT

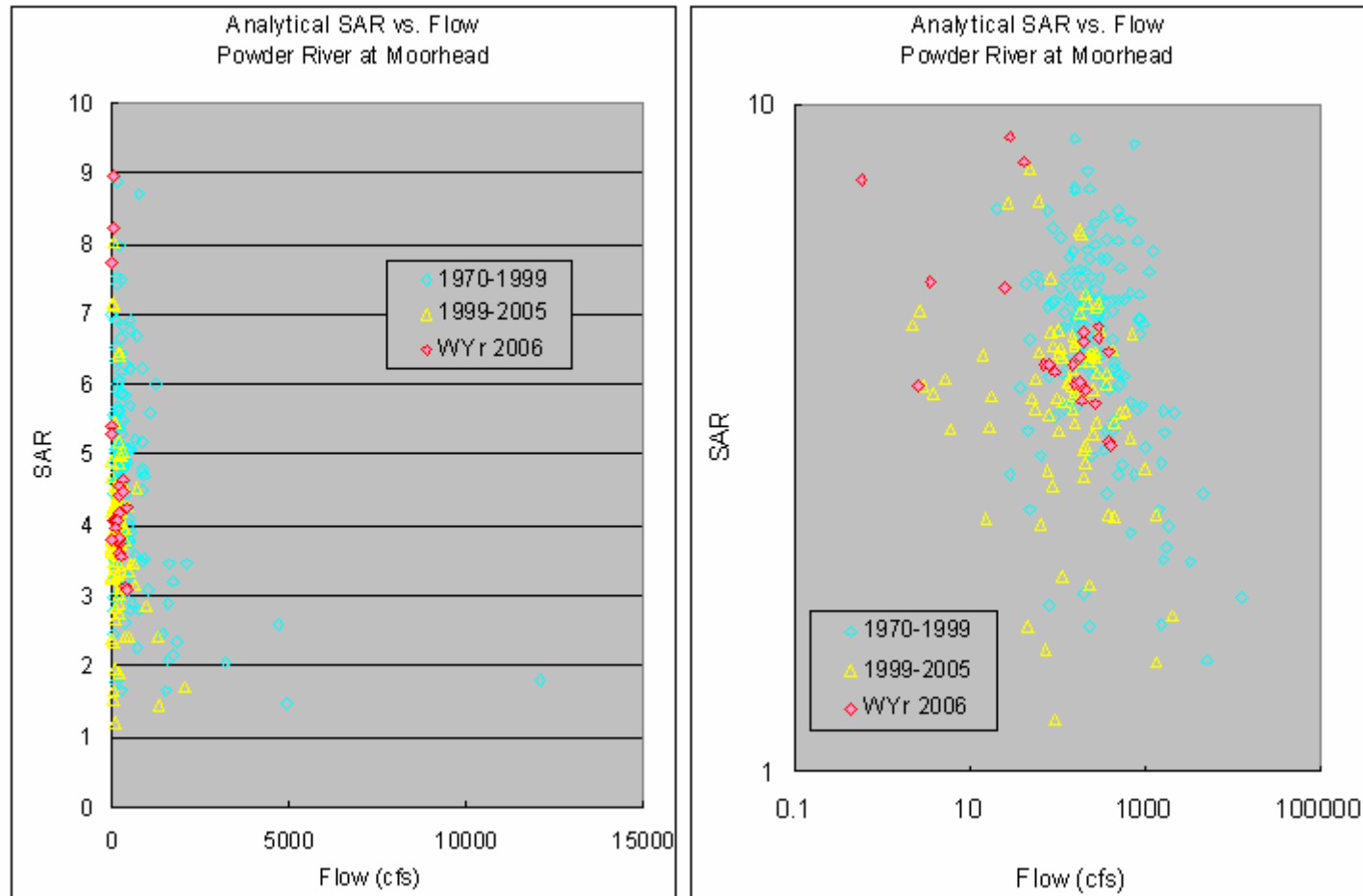


Figure 22 shows analytical SAR vs. Flow data for water year 2006 for the Powder River at Moorhead. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 23: Powder River at Moorhead, MT

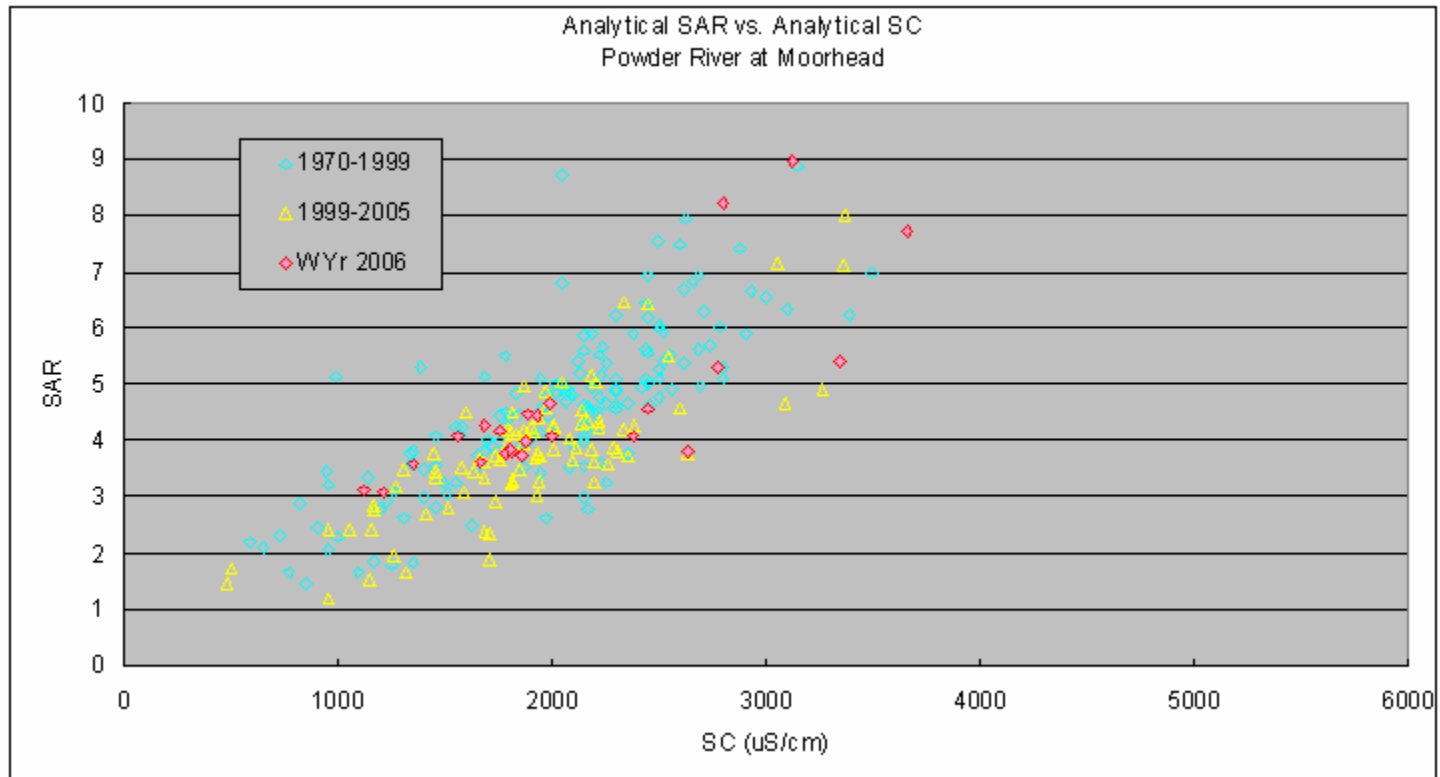


Figure 23 shows analytical SAR vs. analytical SC data for water year 2006 for the Powder River at Moorhead. Historical SAR vs. SC data are also shown to place the data in context.

Figure 24: Powder River near Locate, MT

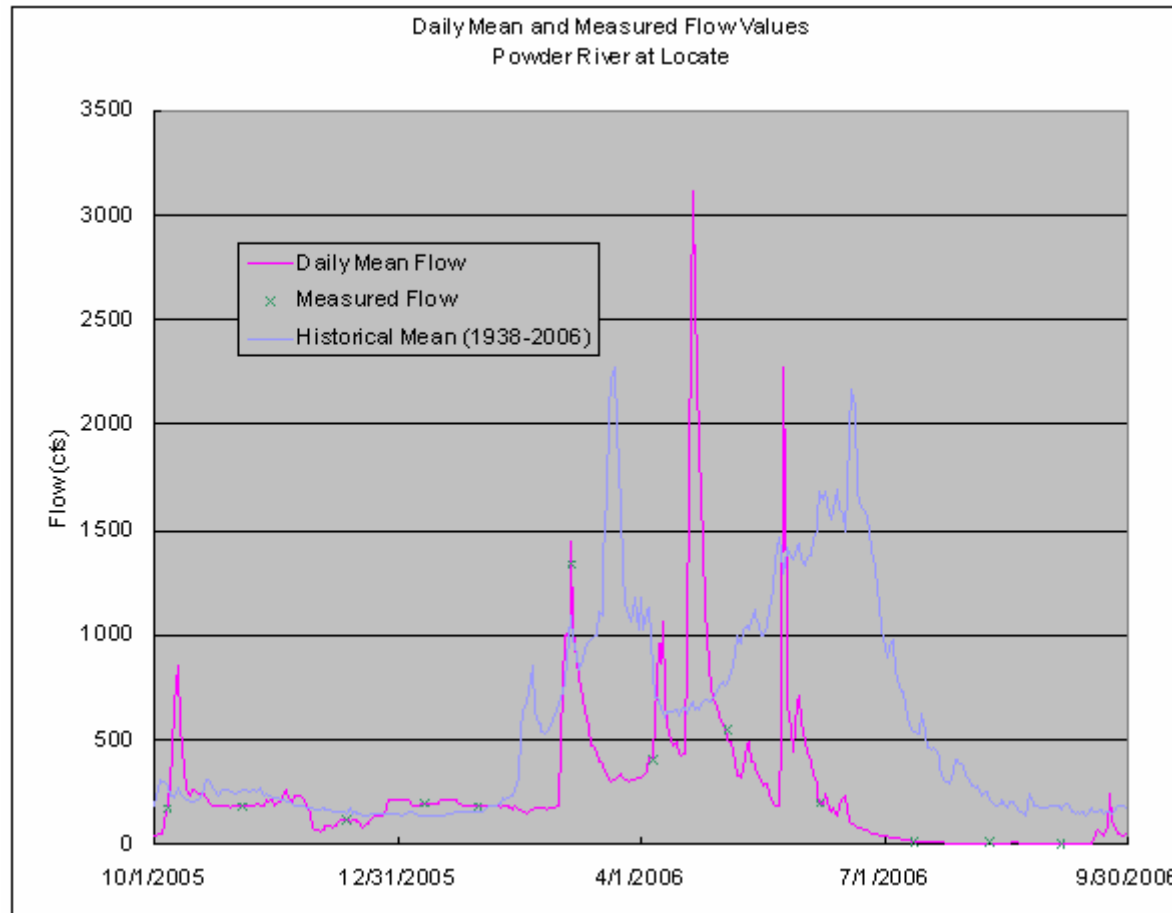


Figure 24 shows mean daily and field measurements of flow in a time series plot for water year 2006 for the Powder River near Locate. Mean daily flow values ranged from 0 to 3120 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 25: Powder River near Locate, MT

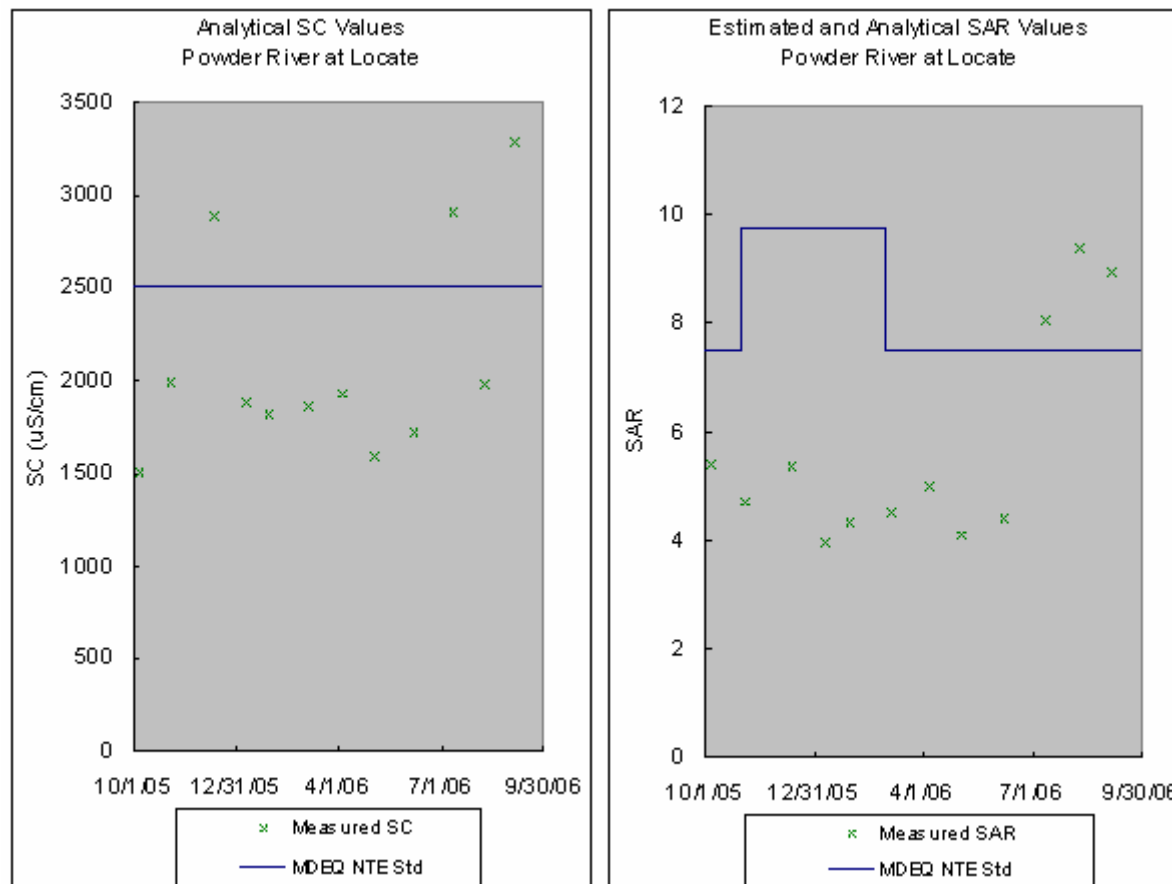


Figure 25 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2006 for the Powder River near Locate. SC values ranged from 1510 to 3290 uS/cm. SAR values ranged from 4.0 to 9.4. MDEQ standards are also displayed for comparison.

Figure 26: Powder River near Locate, MT

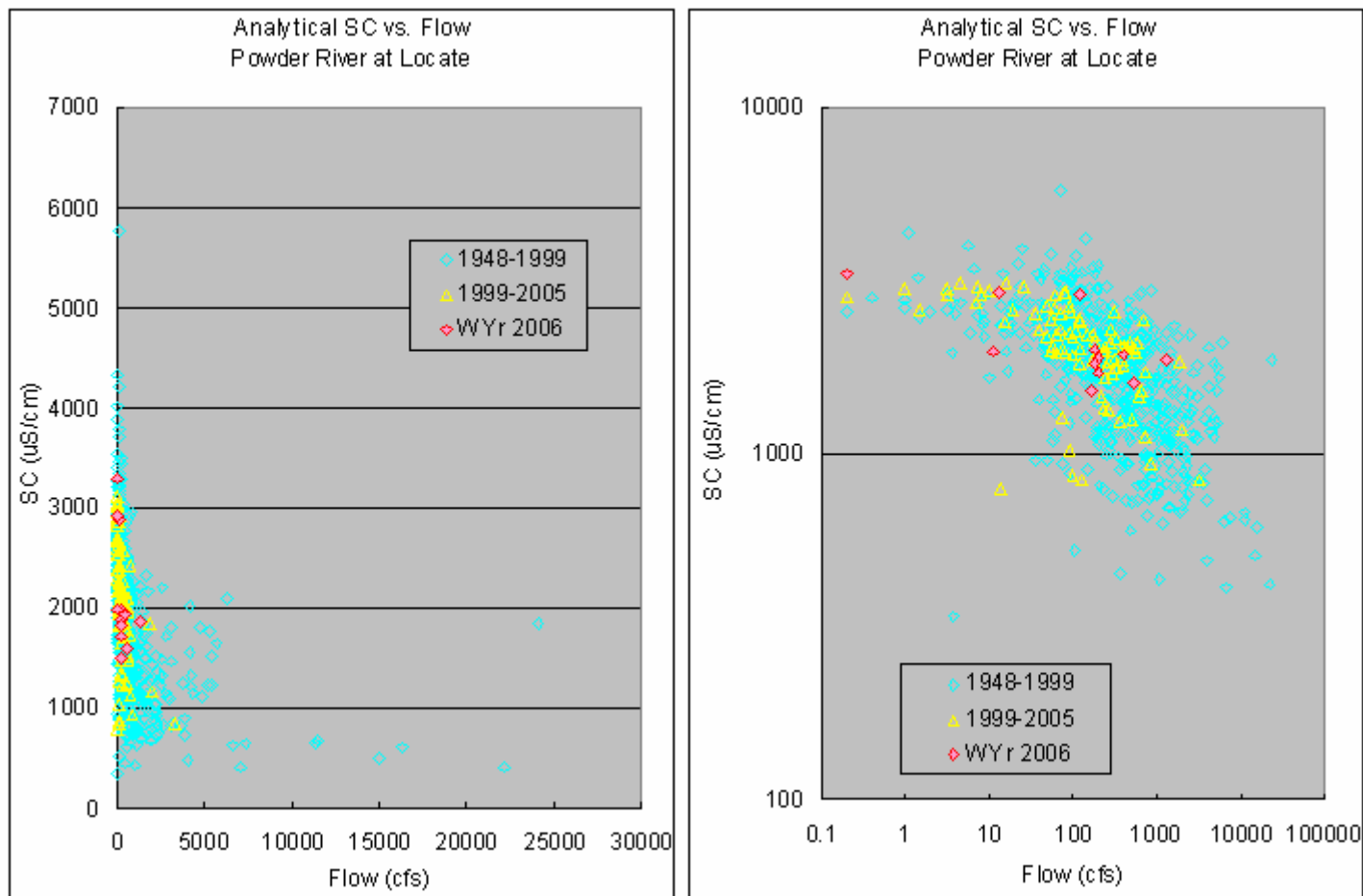


Figure 26 shows analytical SC vs. Flow data for water year 2006 for the Powder River near Locate. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 27: Powder River near Locate, MT

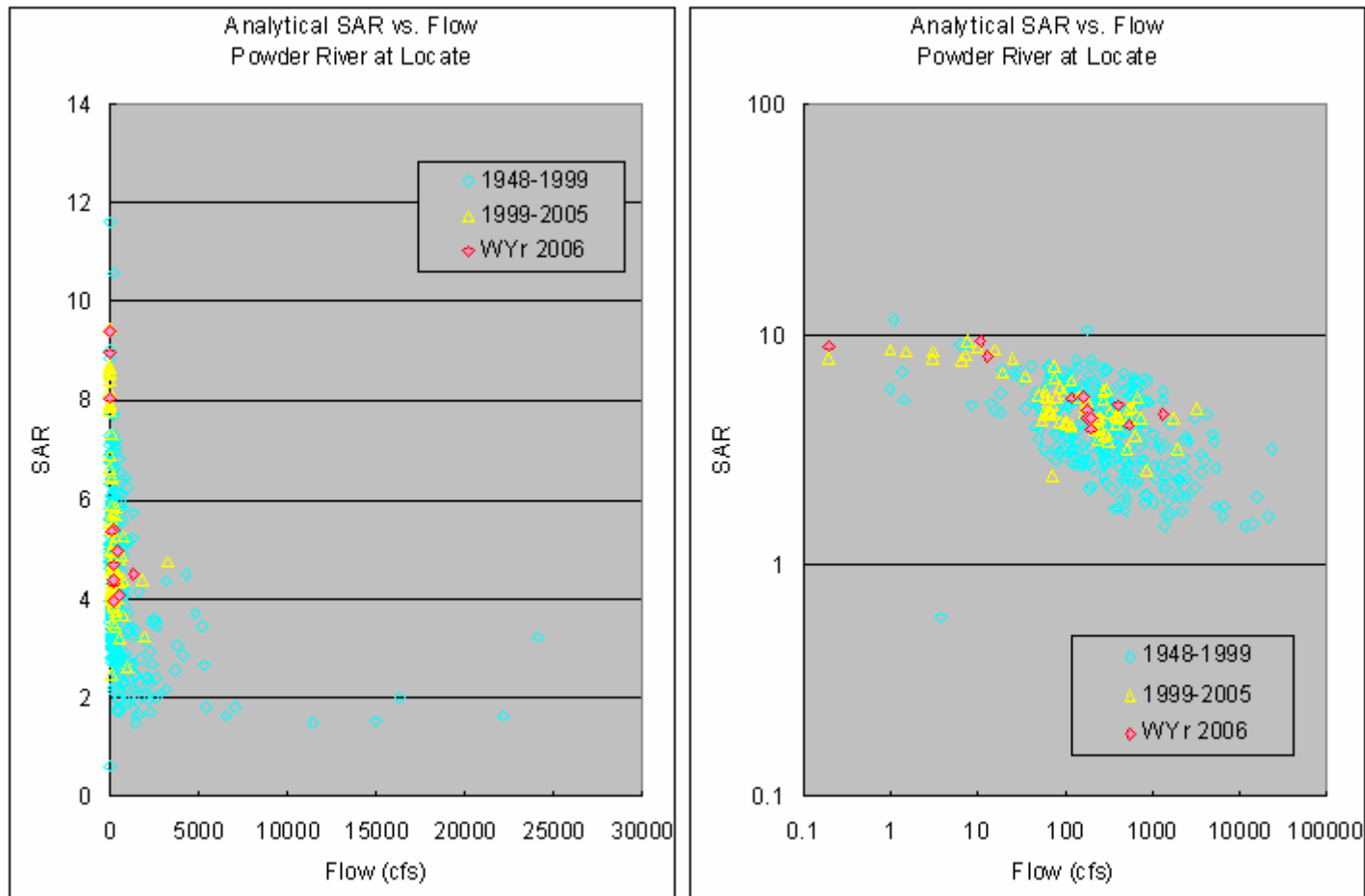


Figure 27 shows analytical SAR vs. Flow data for water year 2006 for the Powder River near Locate. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 28: Powder River near Locate, MT

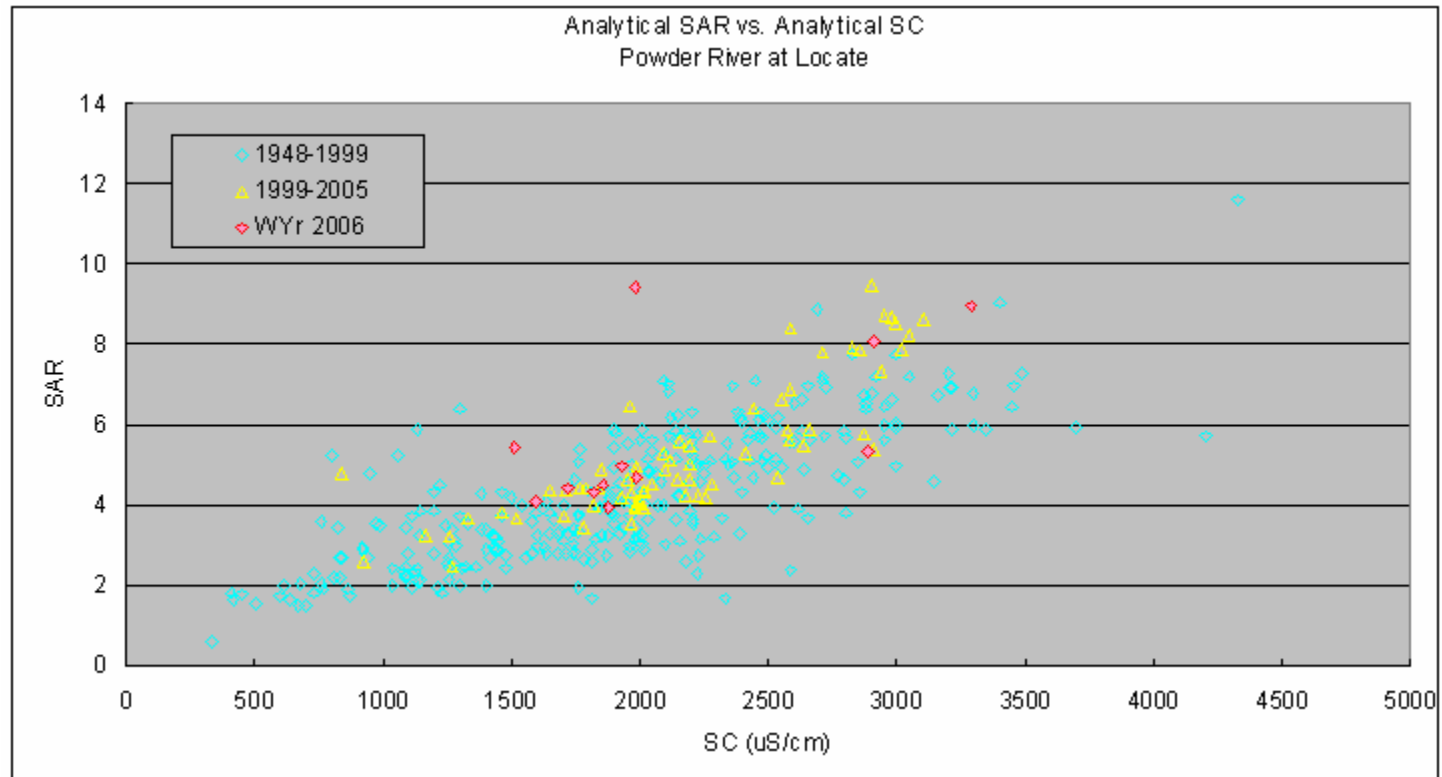


Figure 28 shows analytical SAR vs. analytical SC data for water year 2006 for the Powder River near Locate. Historical SAR vs. SC data are also shown to place the data in context.

Figure 29: Crazy Woman Creek at Upper Station, near Arvada, WY

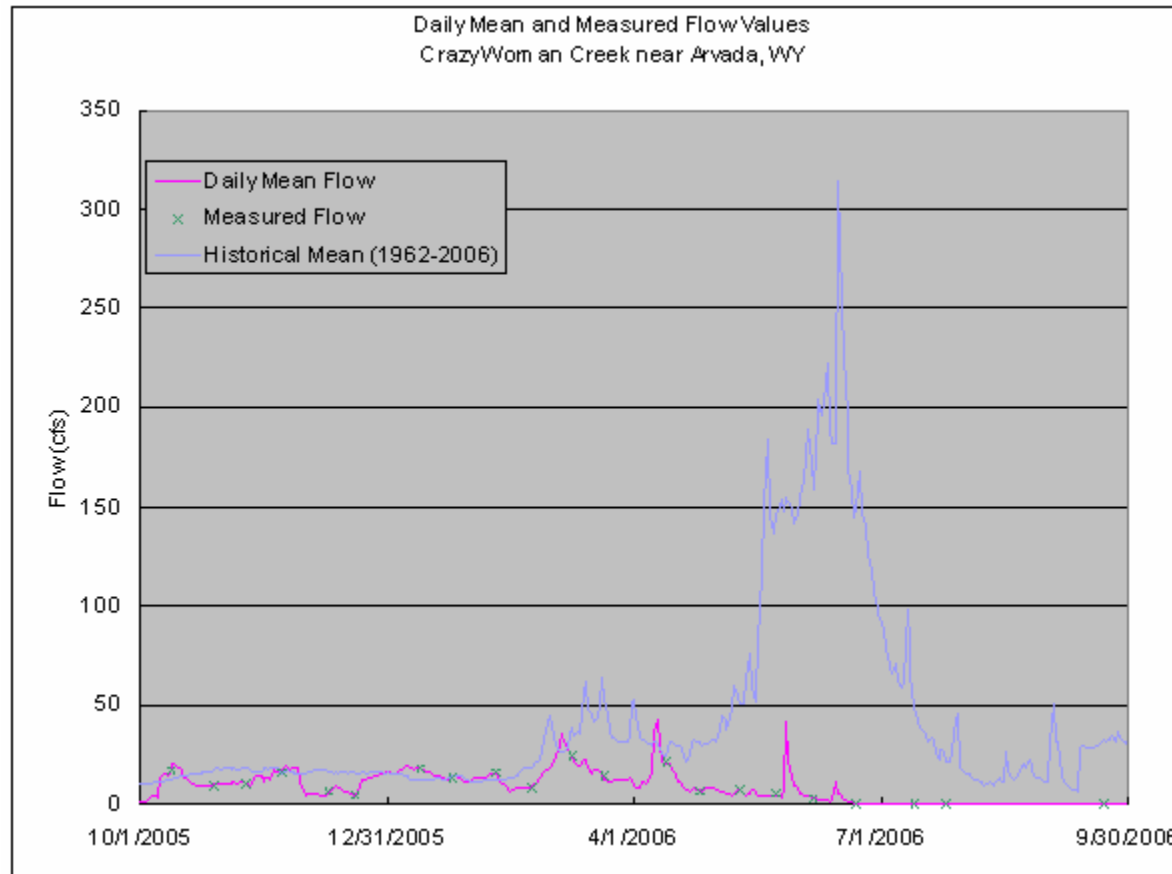


Figure 29 shows mean daily and field measurements of flow in a time series plot for water year 2006 for Crazy Woman near Arvada. Mean daily flow values ranged from 0 to 42 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 30: Crazy Woman Creek at Upper Station, near Arvada, WY

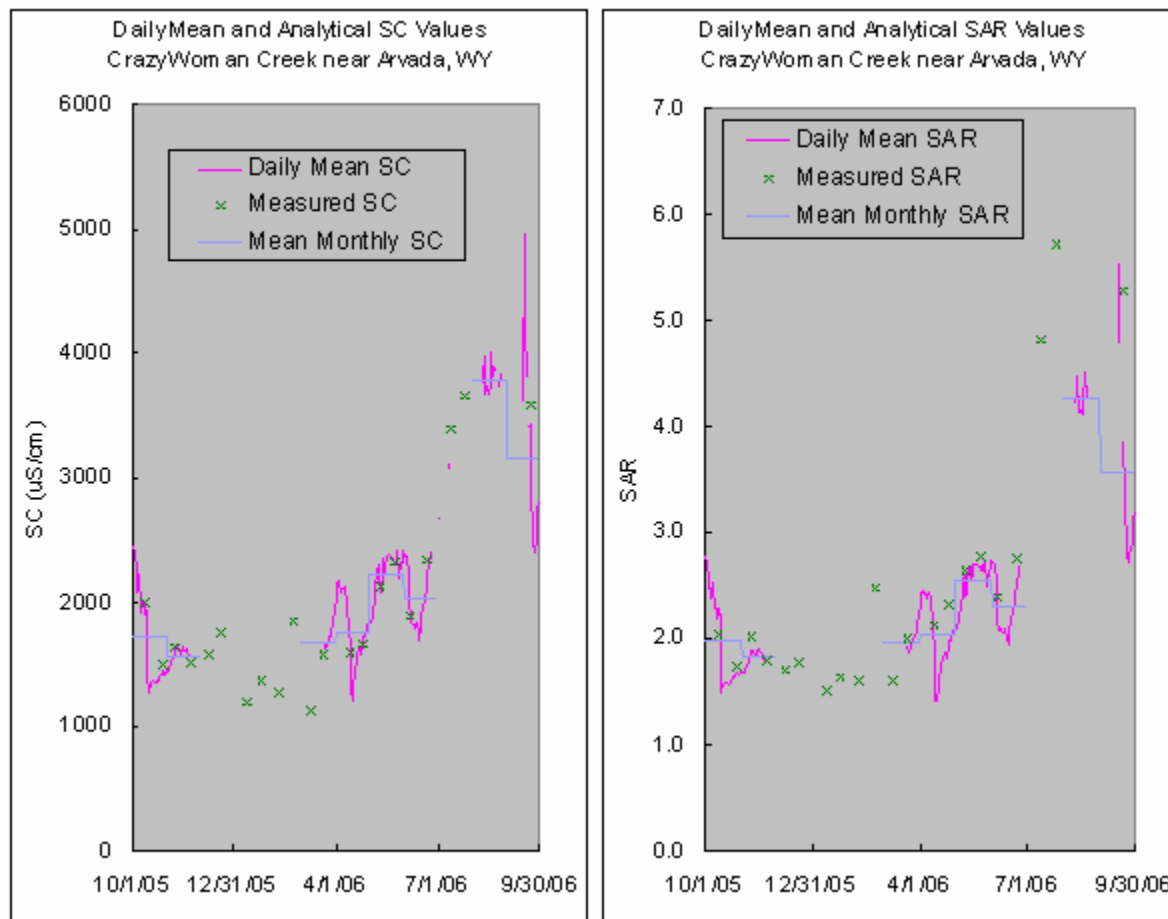


Figure 30 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2006 for Crazy Woman Creek near Arvada. Mean Monthly SC and SAR values are also shown. SC values ranged from 1130 to 4950 $\mu\text{S}/\text{cm}$. SAR values ranged from 1.42 to 5.72.

Figure 31: Crazy Woman Creek at Upper Station, near Arvada, WY

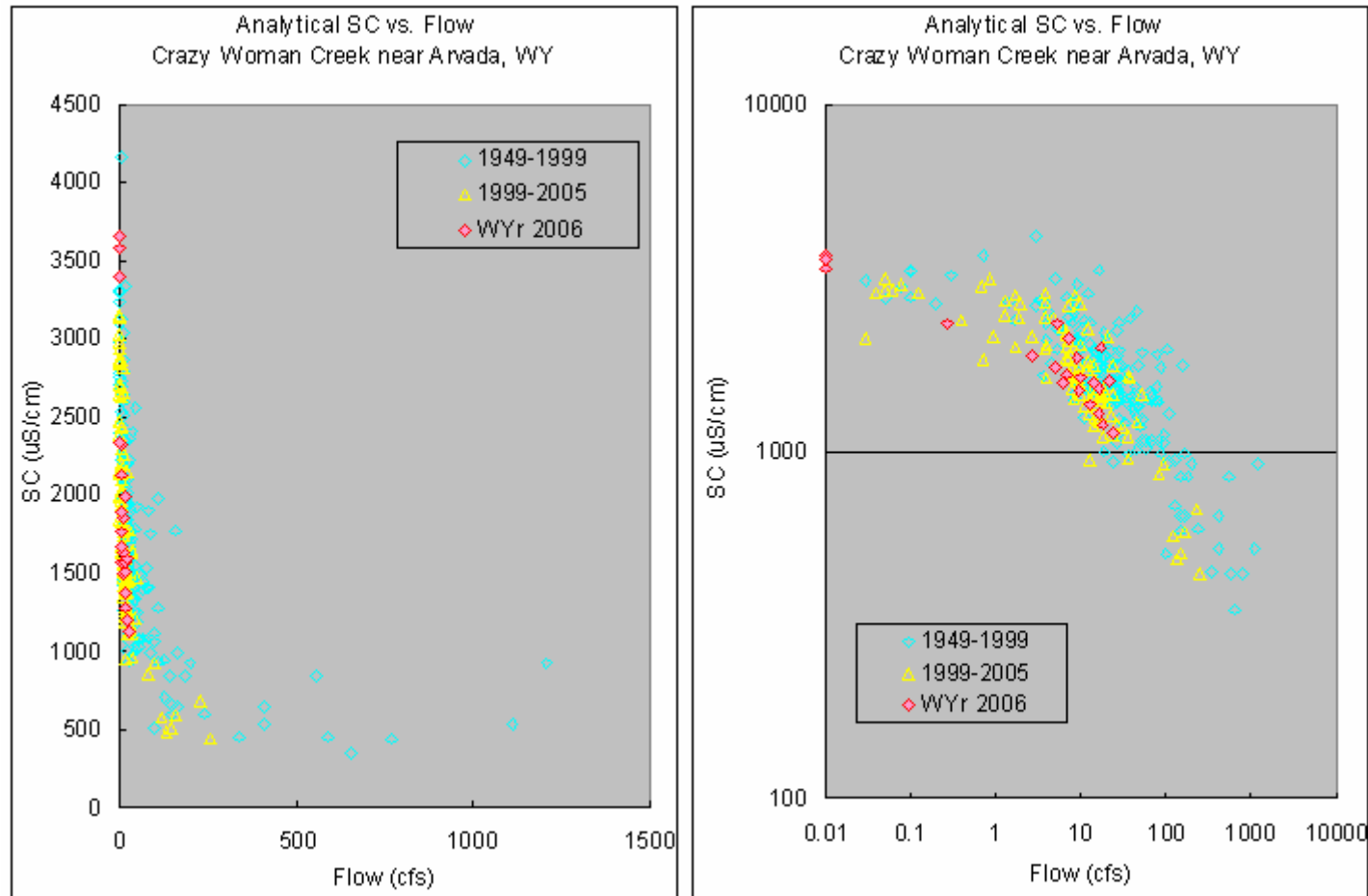


Figure 31 shows analytical SC vs. Flow data for water year 2006 for Crazy Woman near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 32: Crazy Woman Creek at Upper Station, near Arvada, WY

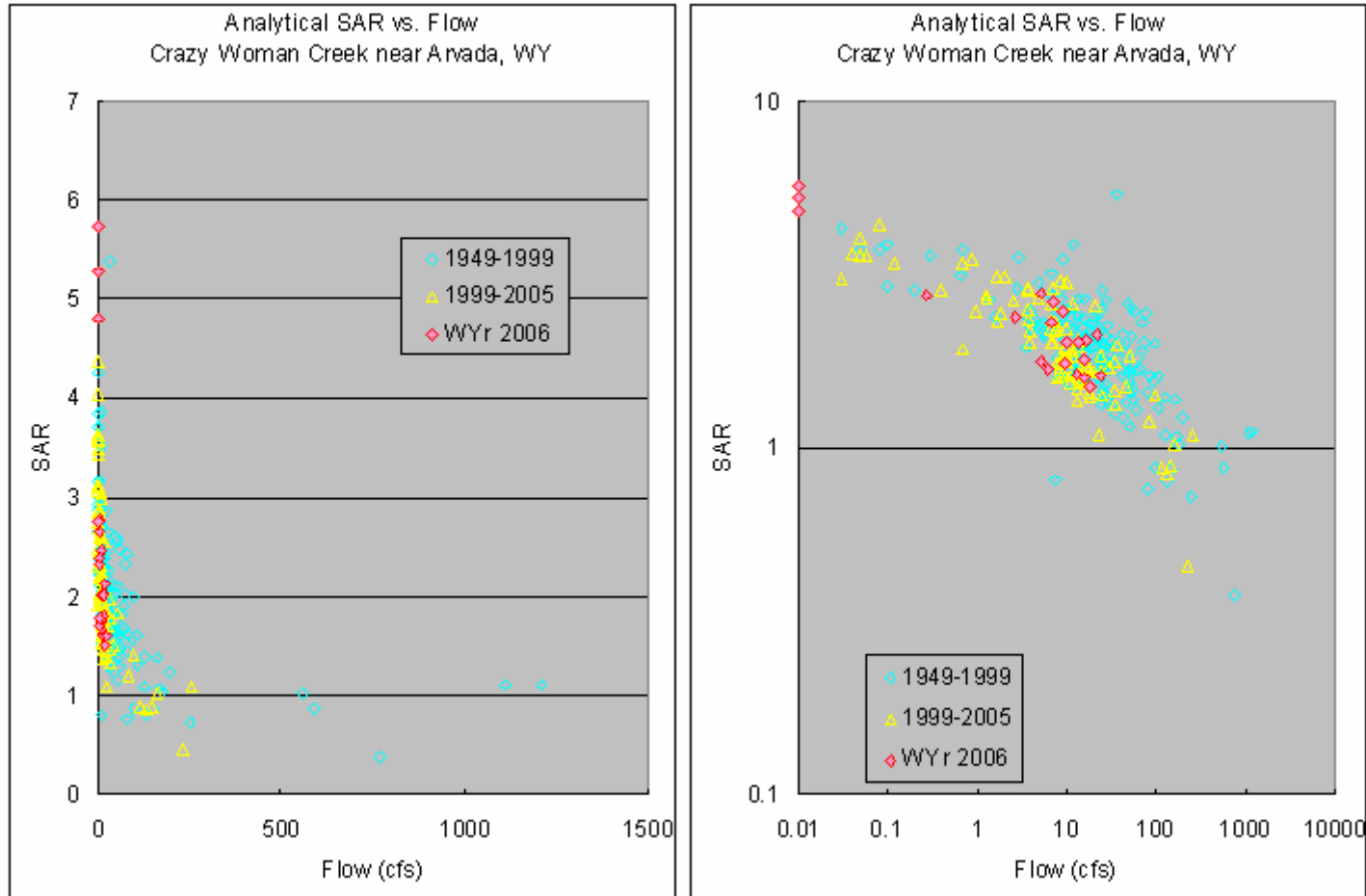


Figure 32 shows analytical SAR vs. Flow data for water year 2006 for Crazy Woman near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 33: Crazy Woman Creek at Upper Station, near Arvada, WY

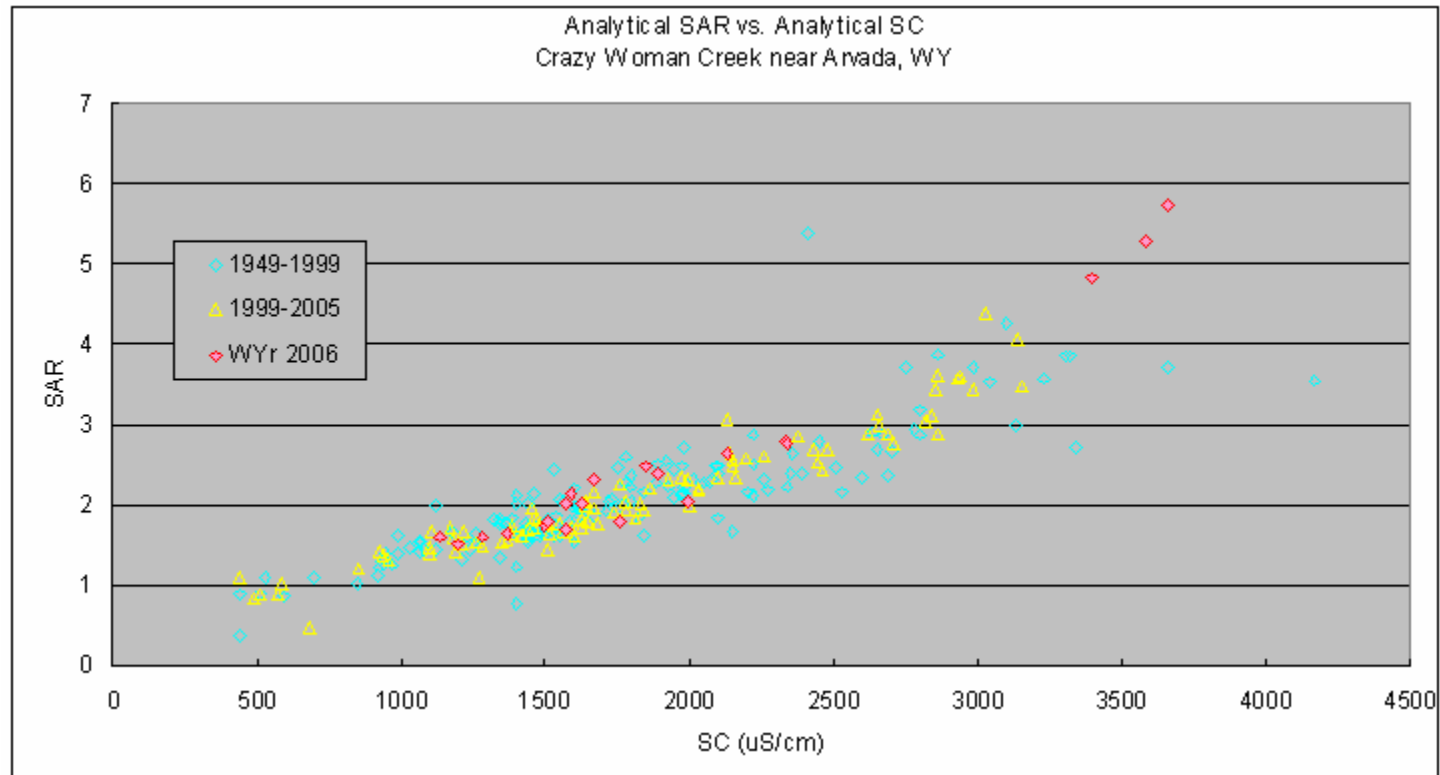


Figure 34: Clear Creek near Arvada, WY

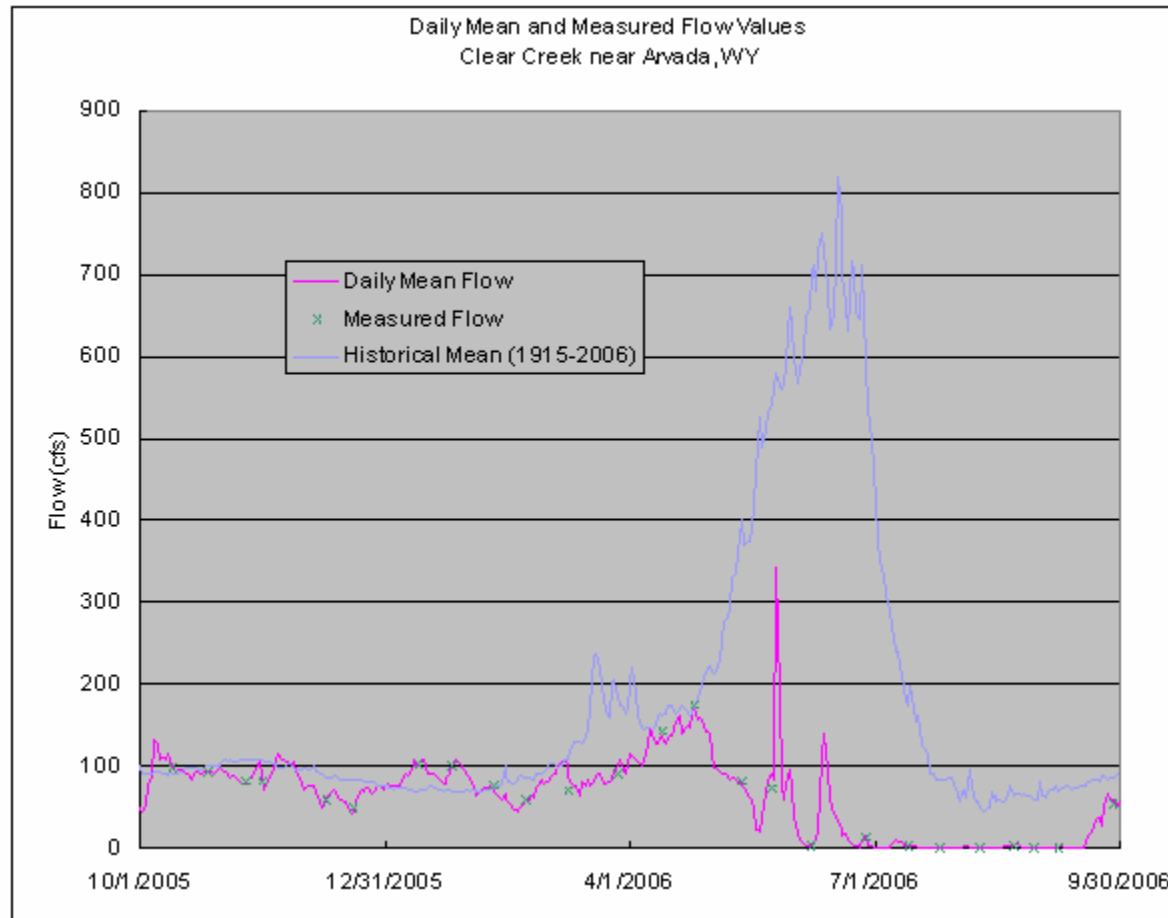


Figure 34 shows mean daily and field measurements of flow in a time series plot for water year 2006 for Clear Creek near Arvada. Mean daily flow values ranged from 0 to 340 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 35: Clear Creek near Arvada, WY

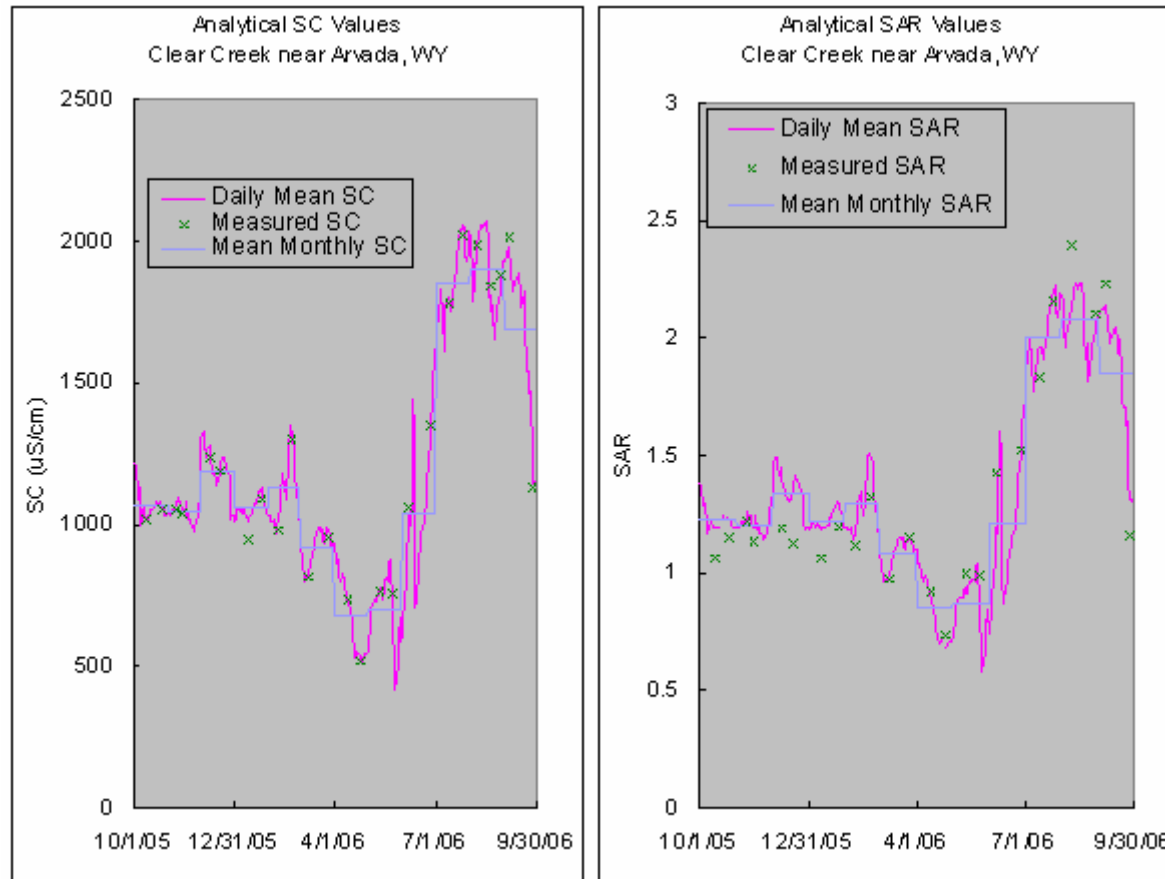


Figure 35 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2006 for Clear Creek near Arvada. Mean Monthly SC and SAR values are also shown. SC values ranged from 412 to 2070 uS/cm. SAR values ranged from 0.6 to 2.4.

Figure 36: Clear Creek near Arvada, WY

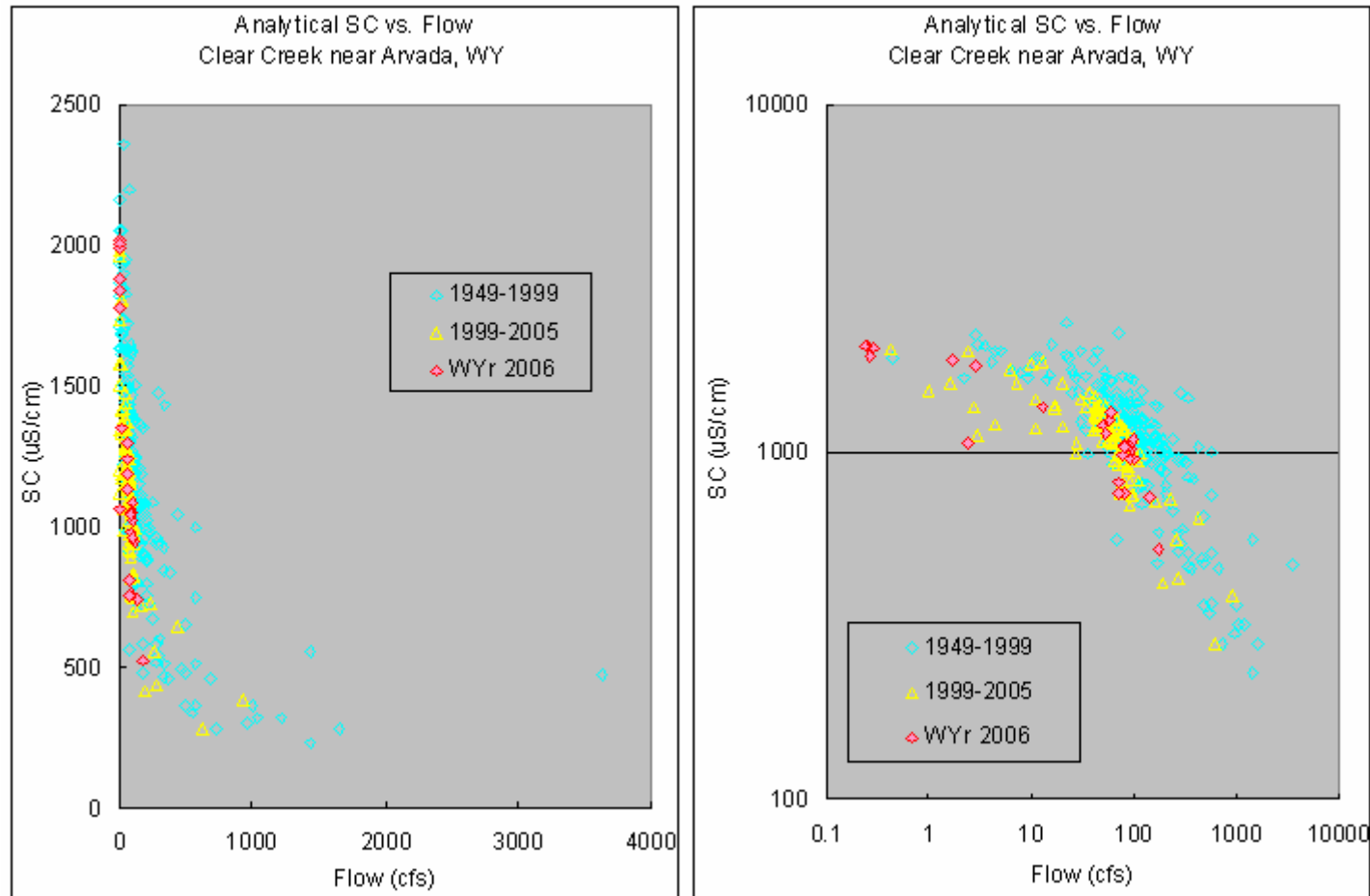


Figure 36 shows analytical SC vs. Flow data for water year 2006 for Clear Creek near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 37: Clear Creek near Arvada, WY

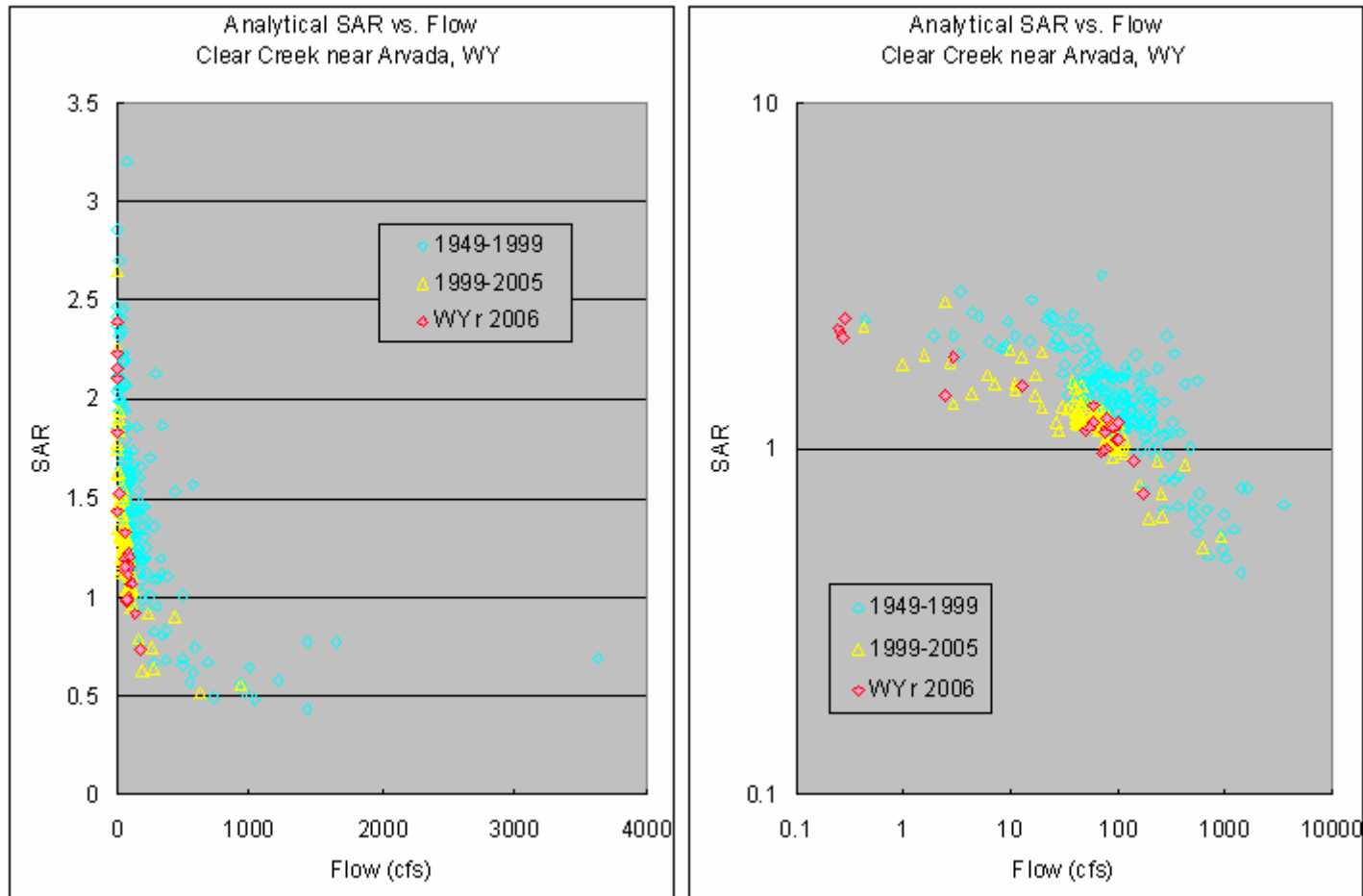


Figure 37 shows analytical SAR vs. Flow data for water year 2006 for Clear Creek near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 38: Clear Creek near Arvada, WY

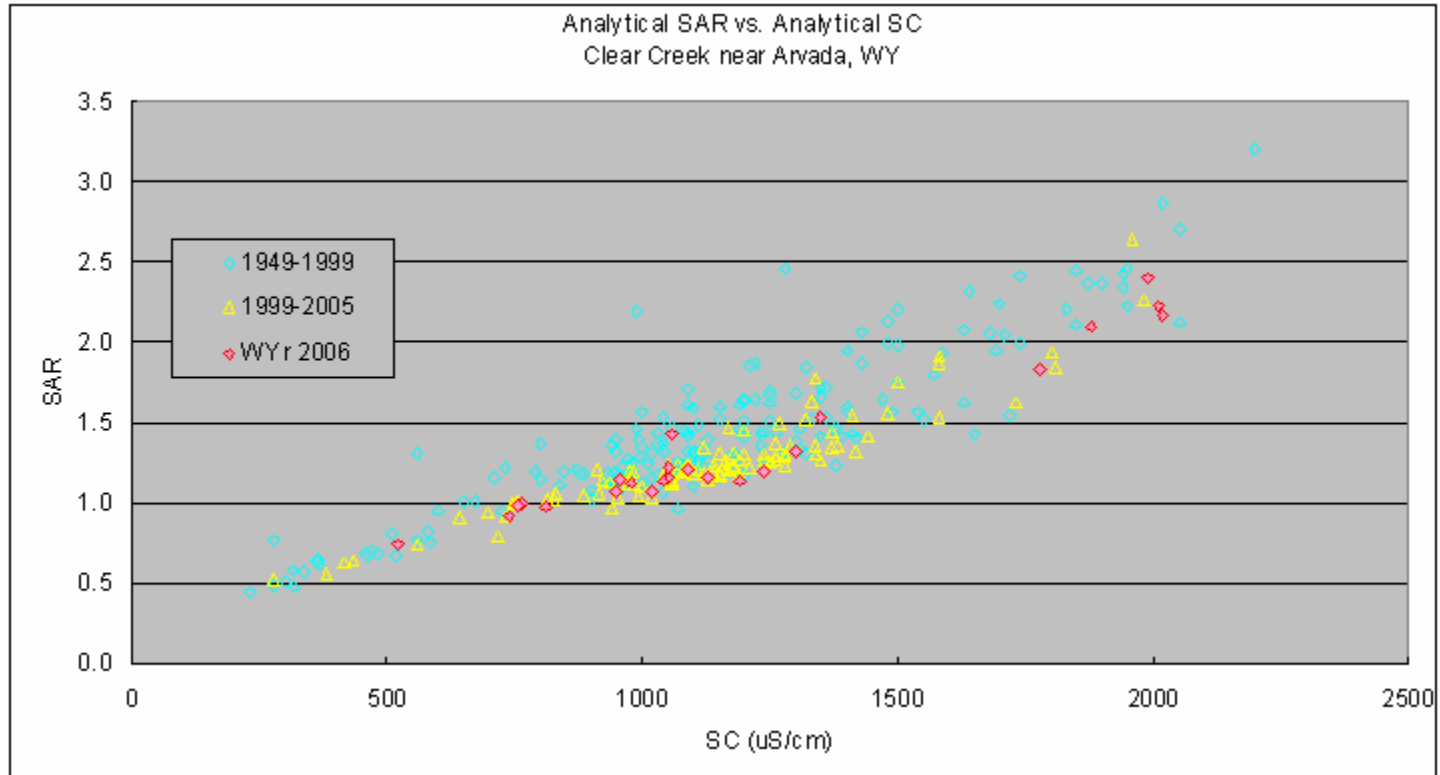


Figure 38 shows analytical SAR vs. analytical SC data for water year 2006 for Clear Creek near Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 39: Little Powder River above Dry Creek, near Weston, WY

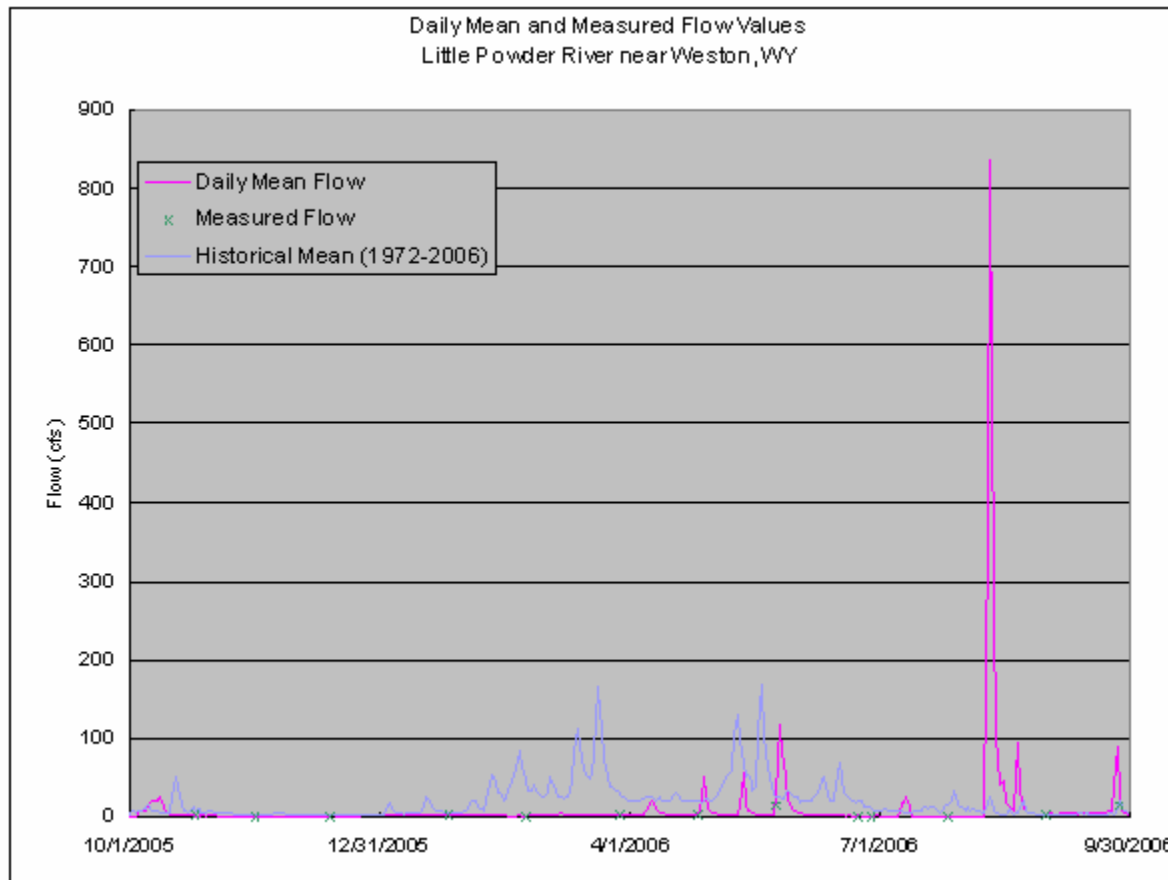


Figure 39 shows mean daily and field measurements of flow in a time series plot for water year 2006 for the Little Powder River near Weston. Mean daily flow values ranged from 0 to 837 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 40: Little Powder River above Dry Creek, near Weston, WY

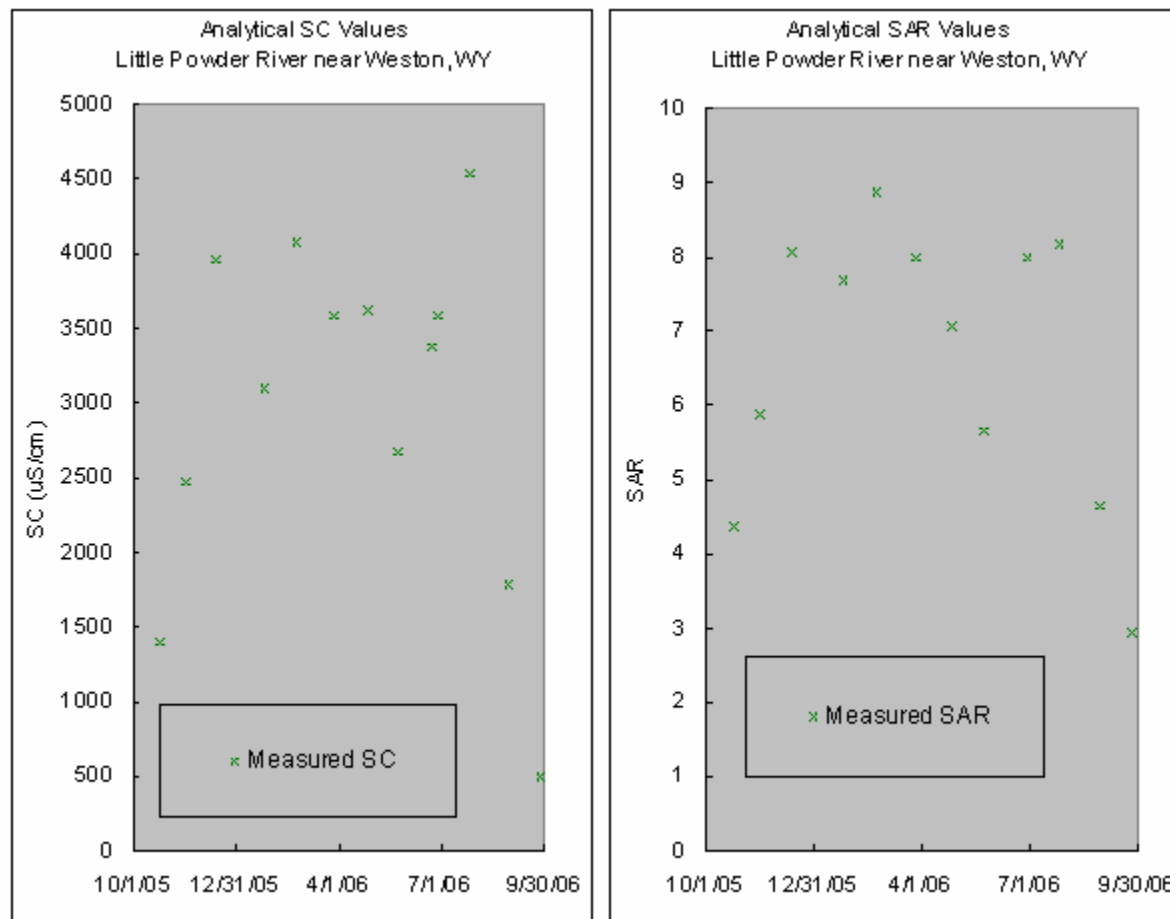


Figure 40 shows analytical SC values (A) and analytical SAR values (B) in time series plots for water year 2005 for the Little Powder River near Weston. SC values ranged from 500 to 4540 uS/cm. SAR values ranged from 3.0 to 8.9.

Figure 41: Little Powder River above Dry Creek, near Weston, WY

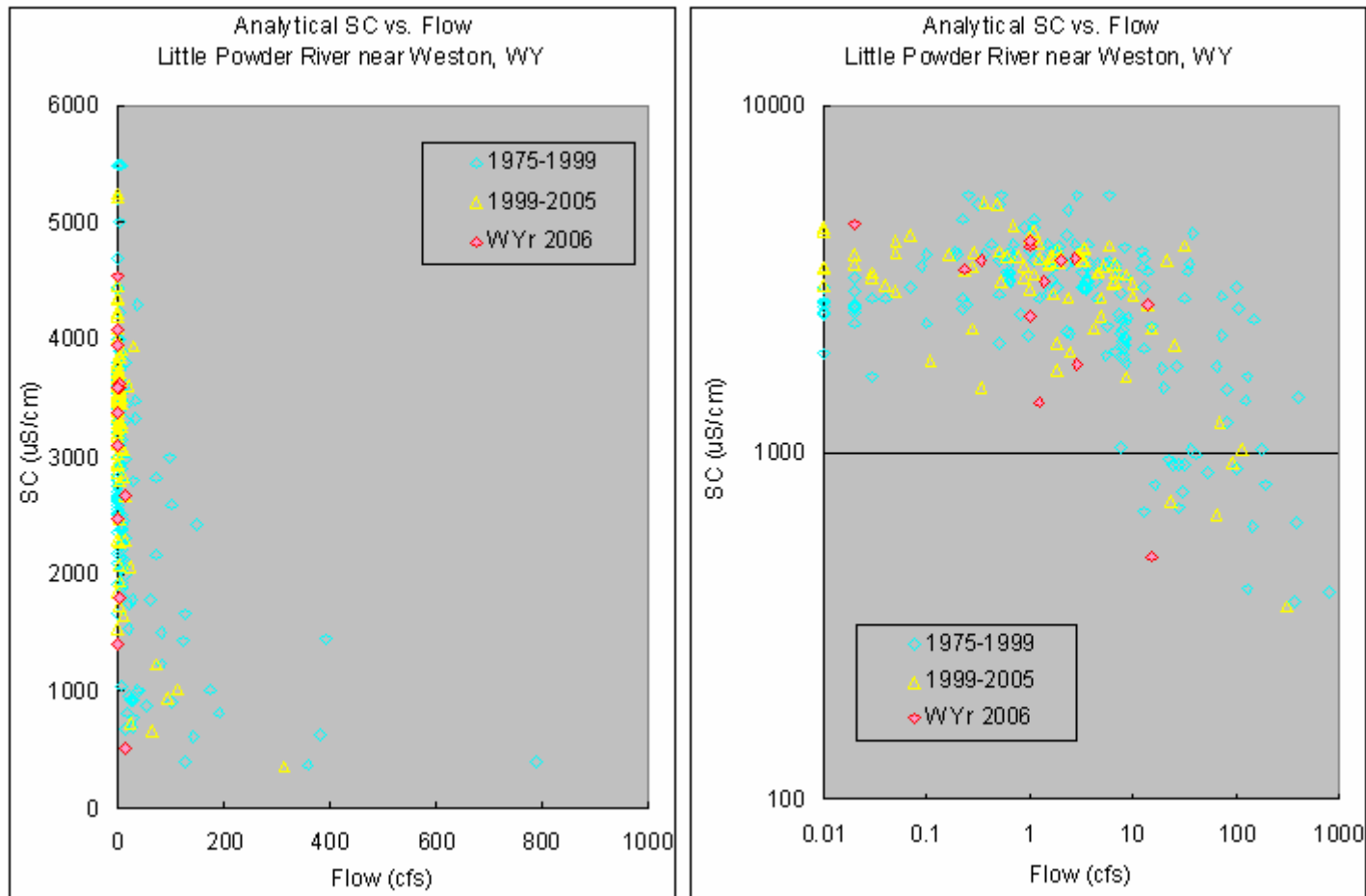


Figure 41 shows analytical SC vs. Flow data for water year 2006 for the Little Powder River near Weston. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 42: Little Powder River above Dry Creek, near Weston, WY

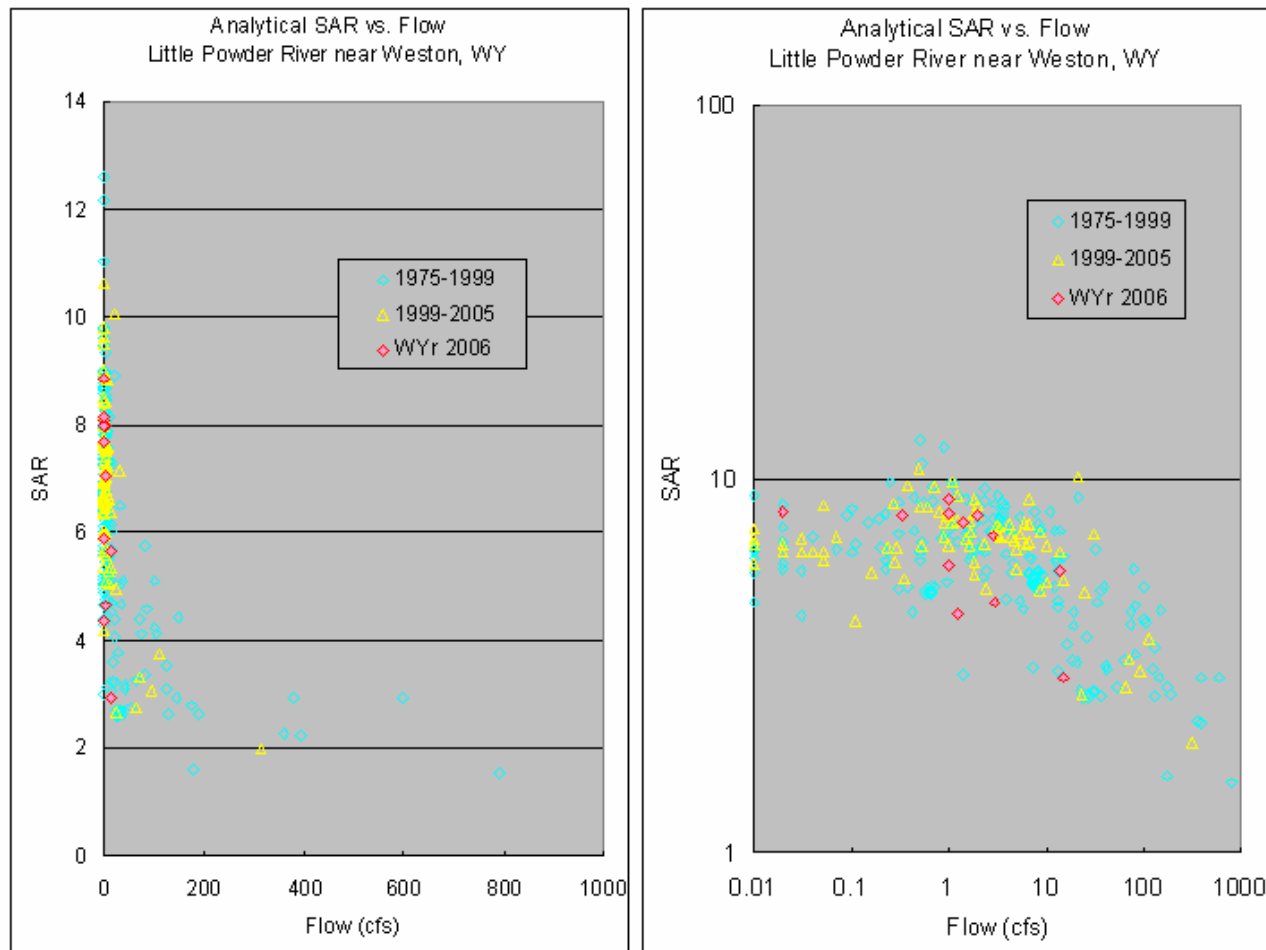


Figure 42 shows analytical SAR vs. Flow data for water year 2006 for the Little Powder River near Weston. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 43: Little Powder River above Dry Creek, near Weston, WY

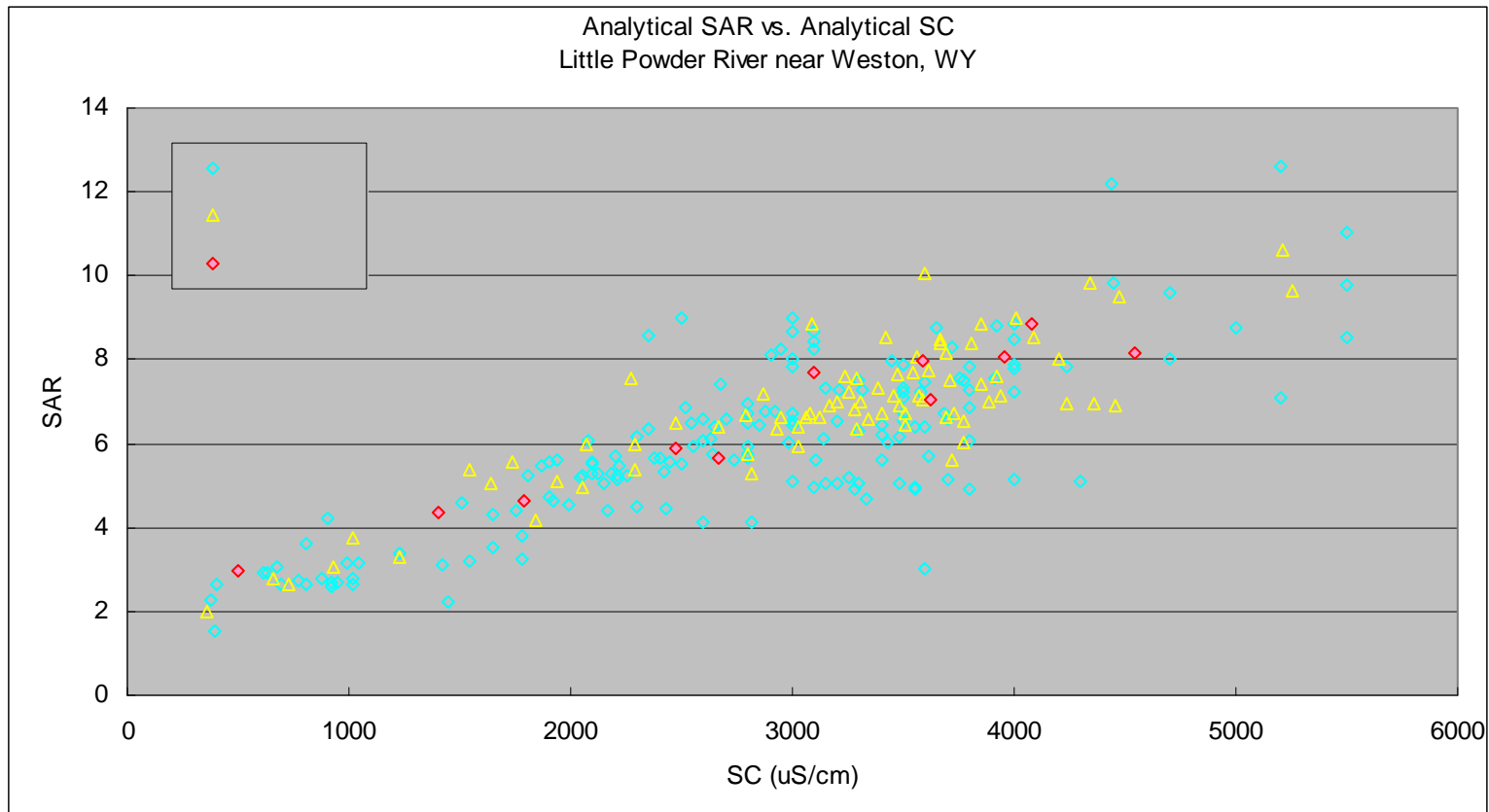


Figure 43 shows analytical SAR vs. analytical SC data for water year 2006 for the Little Powder River near Weston. Historical SAR vs. SC data are also shown to place the data in context.

Figure 44: Little Powder River near Broadus, MT

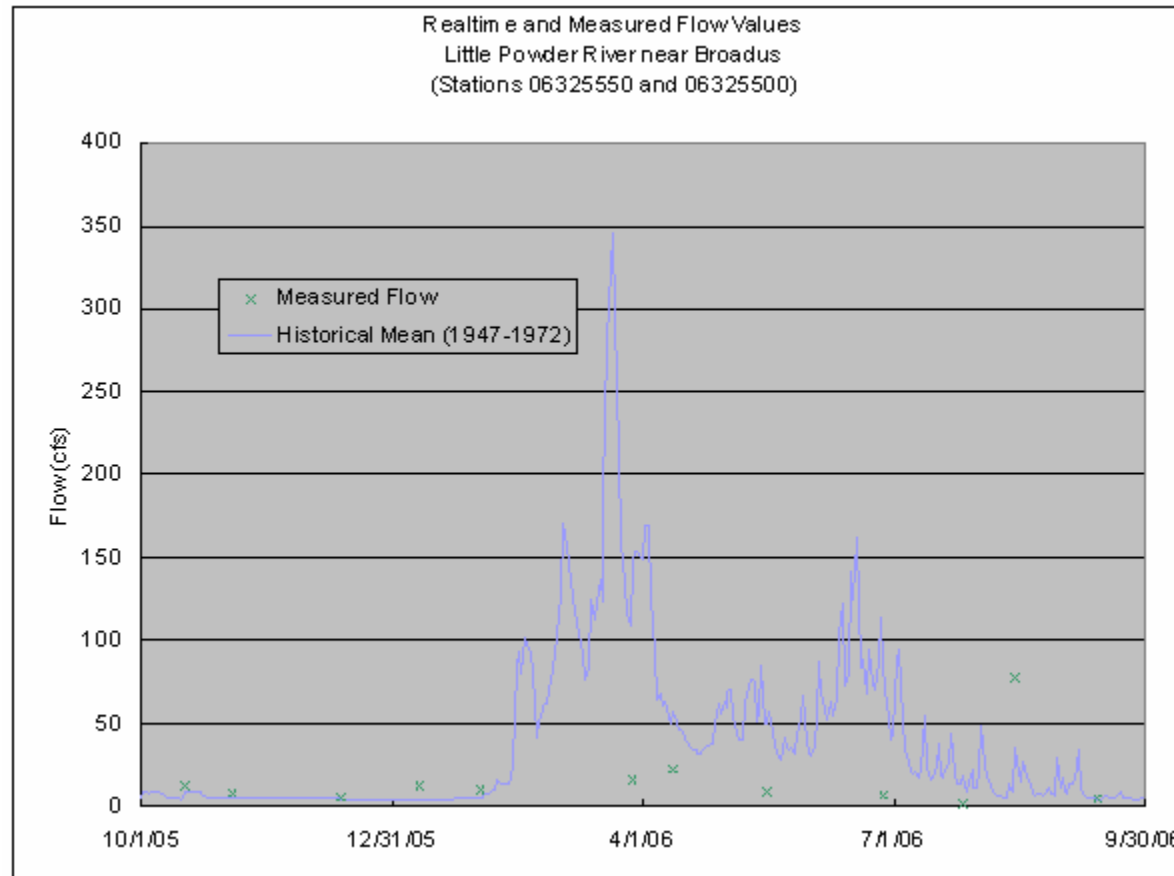


Figure 44 shows field measurements of flow in a time series plot for water year 2006 for the Little Powder River near Broadus. Recorded flow values ranged from 1.4 to 77 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 45: Little Powder River near Broadus, MT

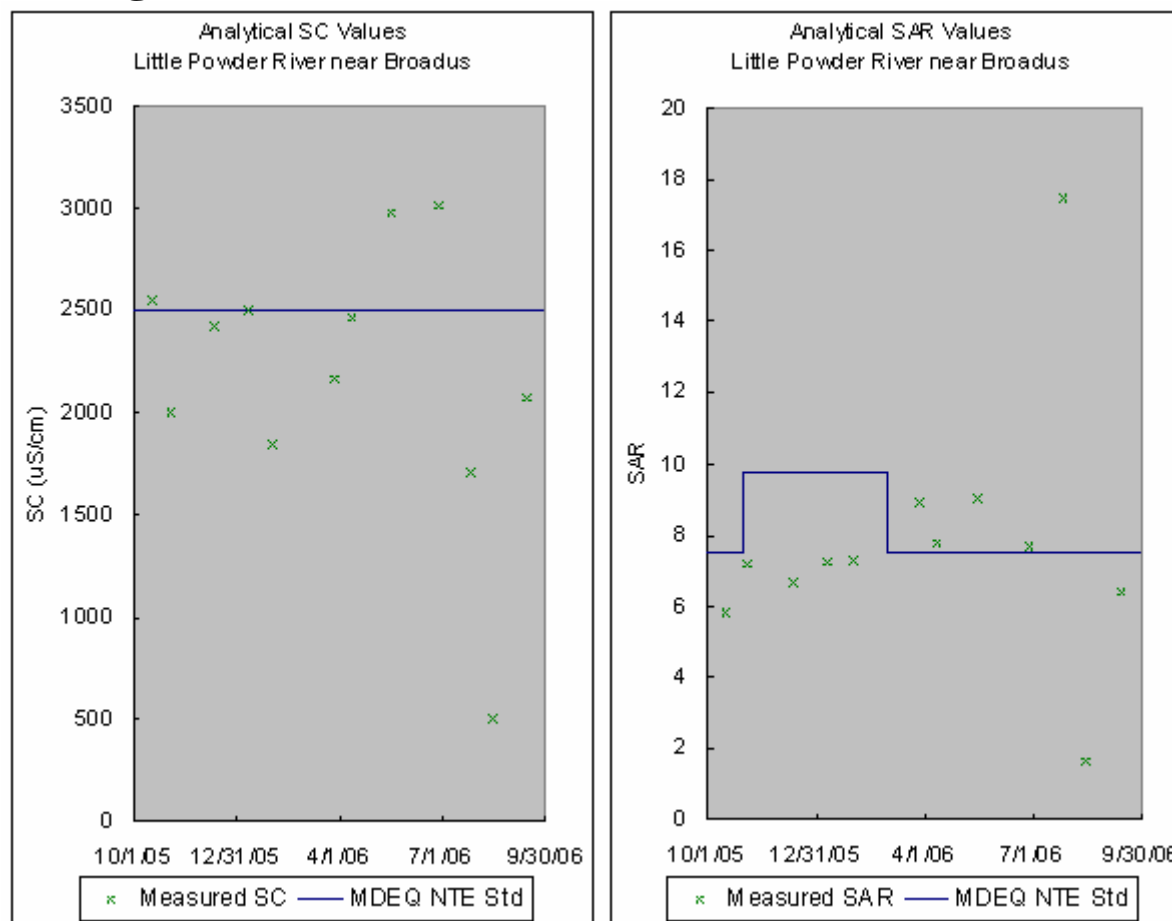


Figure 45 shows analytical SC values (A) and analytical SAR values (B) in time series plots for water year 2006 for the Little Powder River near Broadus. SC values ranged from 500 to 3020 uS/cm. SAR values ranged from 1.6 to 17.5. MDEQ standards are also displayed for comparison.

Figure 46: Little Powder River near Broadus, MT

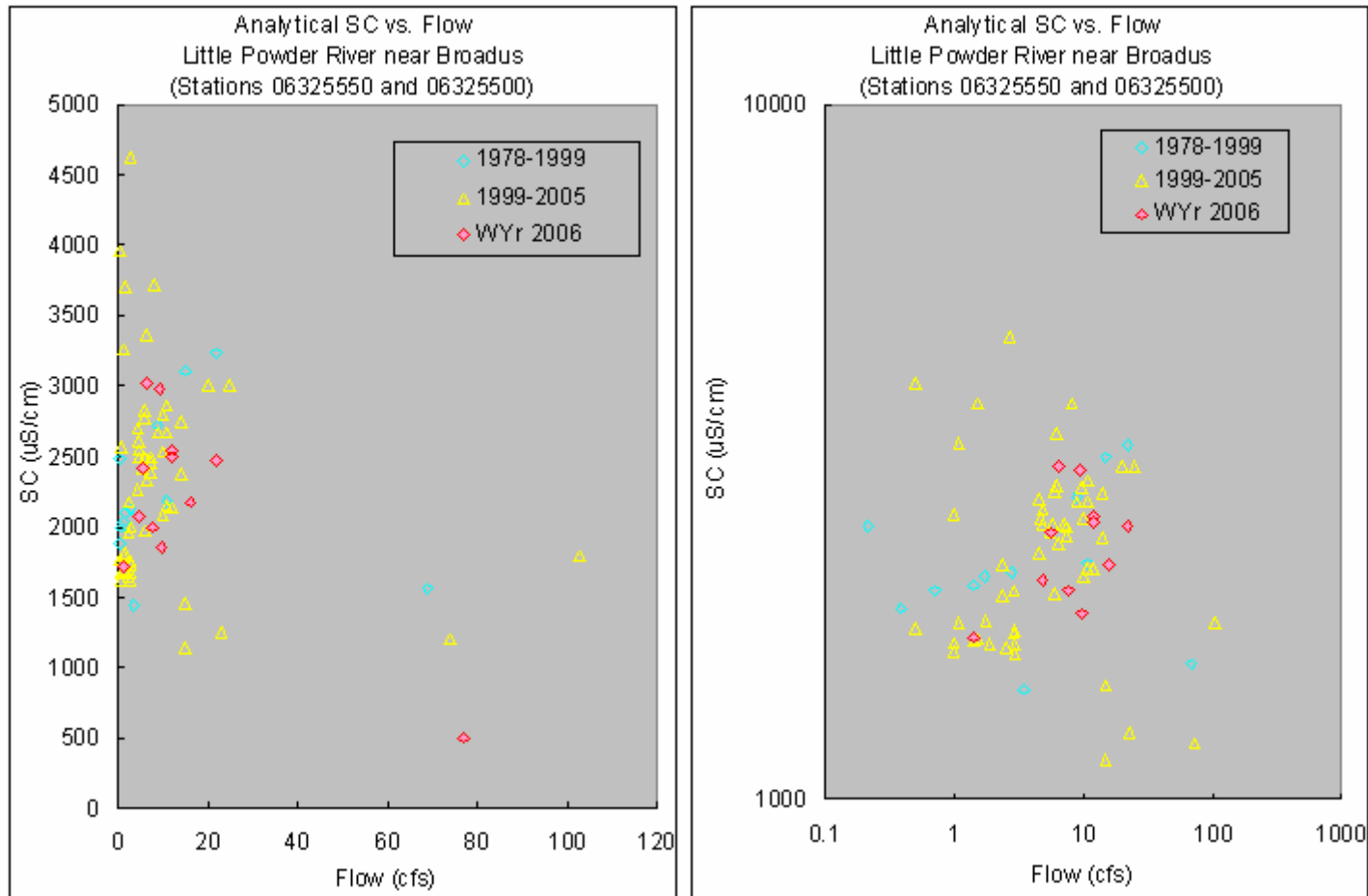


Figure 46 shows analytical SC vs. Flow data for water year 2006 for the Little Powder River near Broadus. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 47: Little Powder River near Broadus, MT

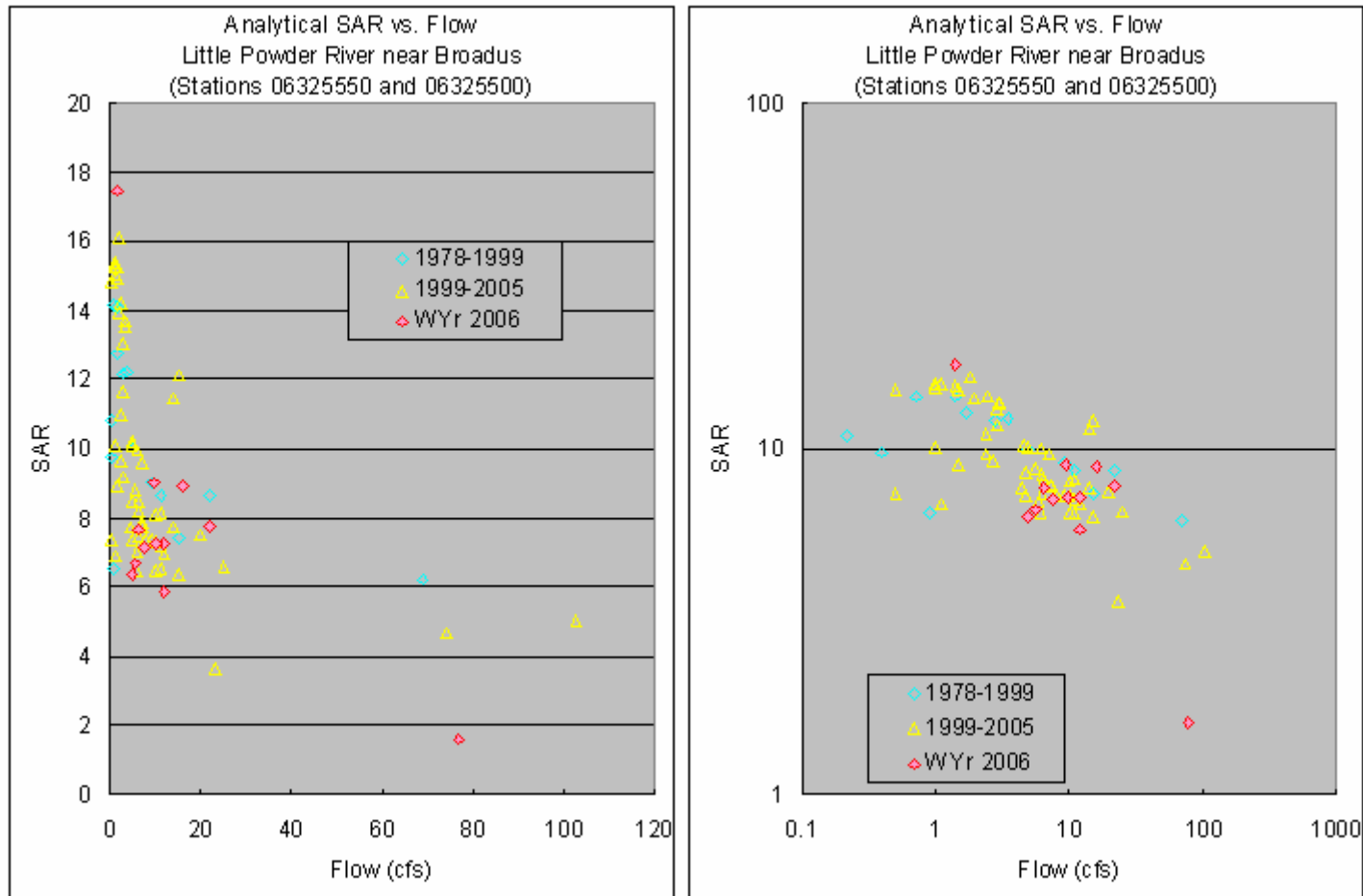


Figure 47 shows analytical SAR vs. Flow data for water year 2006 for the Little Powder River near Broadus. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 48: Little Powder River near Broadus, MT

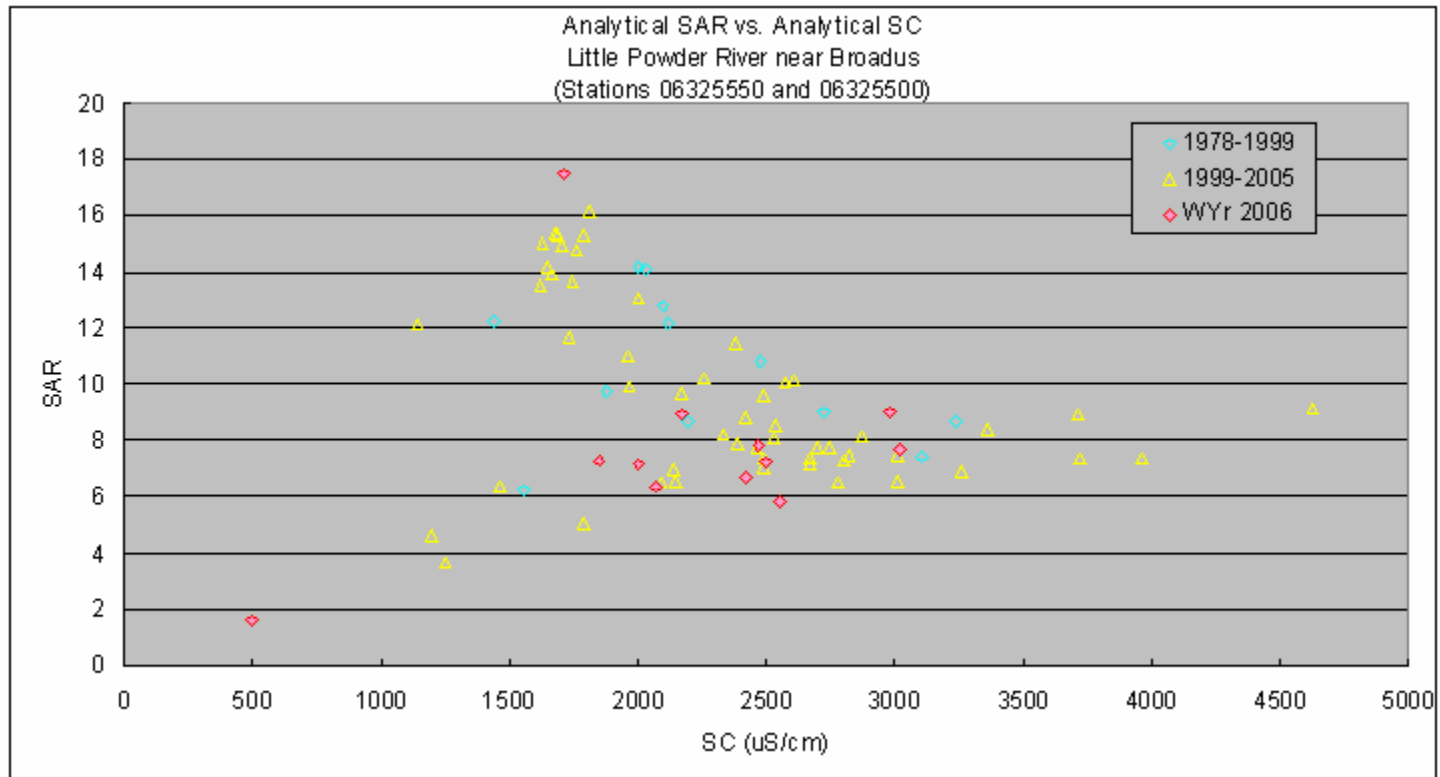


Figure 48 shows analytical SAR vs. analytical SC data for water year 2006 for the Little Powder River near Broadus. Historical SAR vs. SC data are also shown to place the data in context.